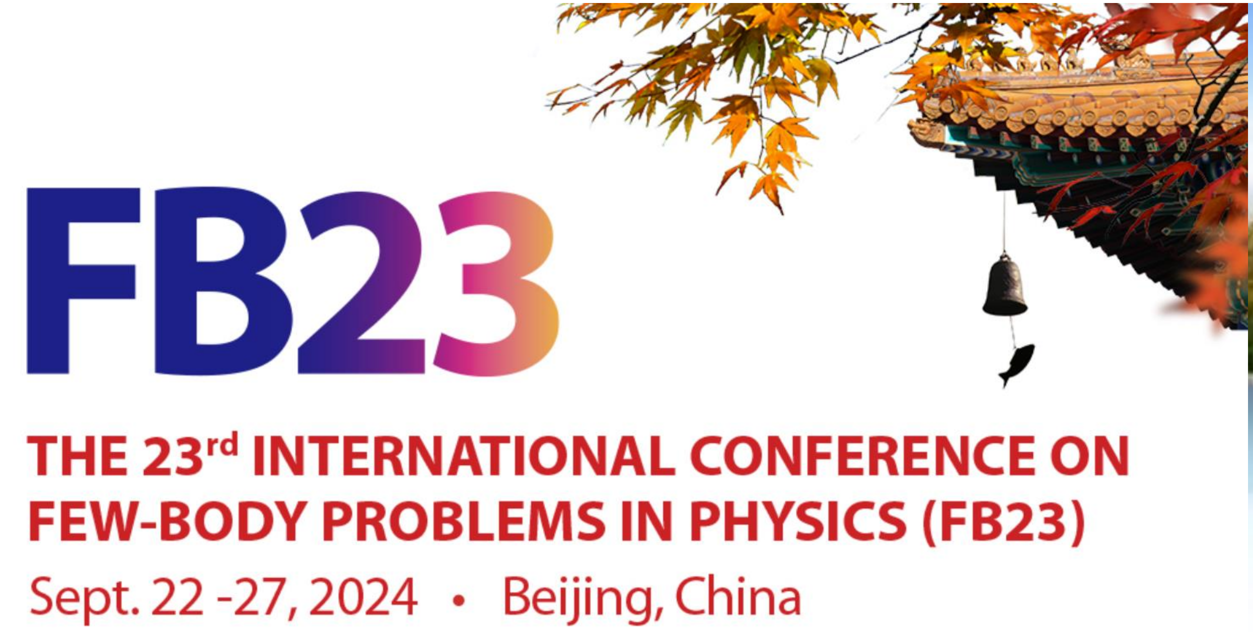
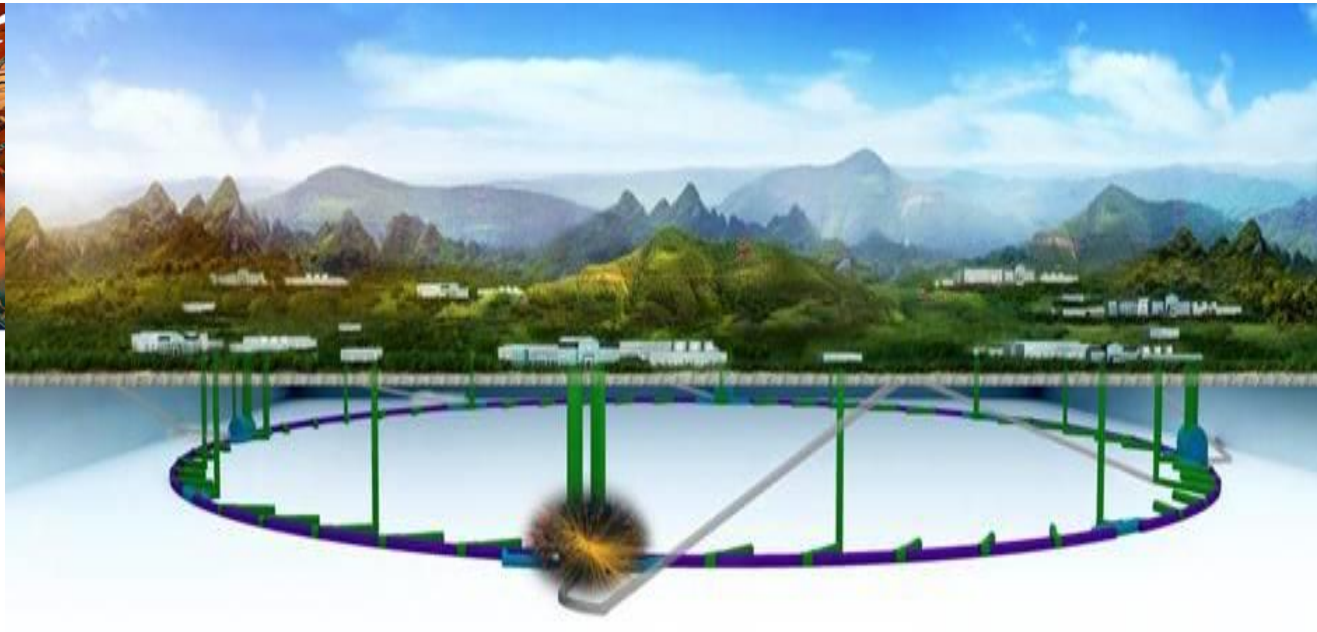
Status of the CEPC Project

Haijun Yang (for the CEPC study group)

上海交通大學 SHANGHAI JIAO TONG UNIVERSITY | 李政道研究所 Tsung-Dao Lee Institute





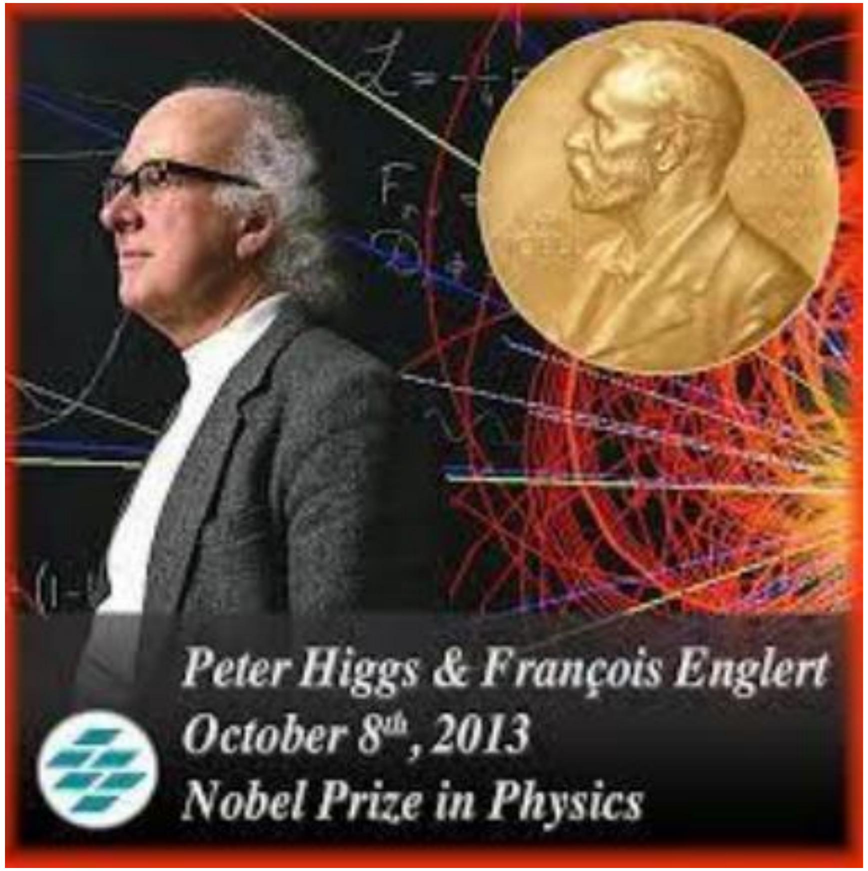
Outline

- From Higgs discovery to Higgs factory
- Introduction to CEPC
  - Goal and major milestones
  - Consensus on Higgs Factory
- CEPC Status and Progress
  - Physics Program
  - Accelerator R&D
  - Detector R&D
- Project Planning and Development
- Summary

Higgs discovery to precision measurements

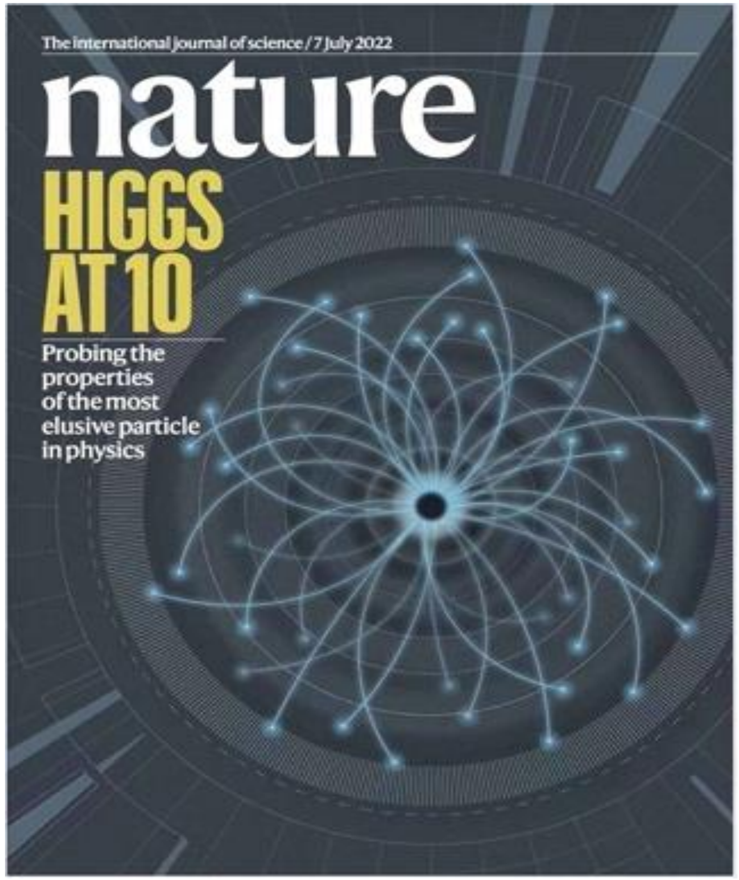
Discovery of Higgs boson

Phys. Lett. B 716 (2012) 1-29
Phys. Lett. B 716 (2012) 30-61
Science 338 (2012) 1569-1575
Science 338 (2012) 1576-1582



2012：Higgs mechanism explains the mass origin of SM particles

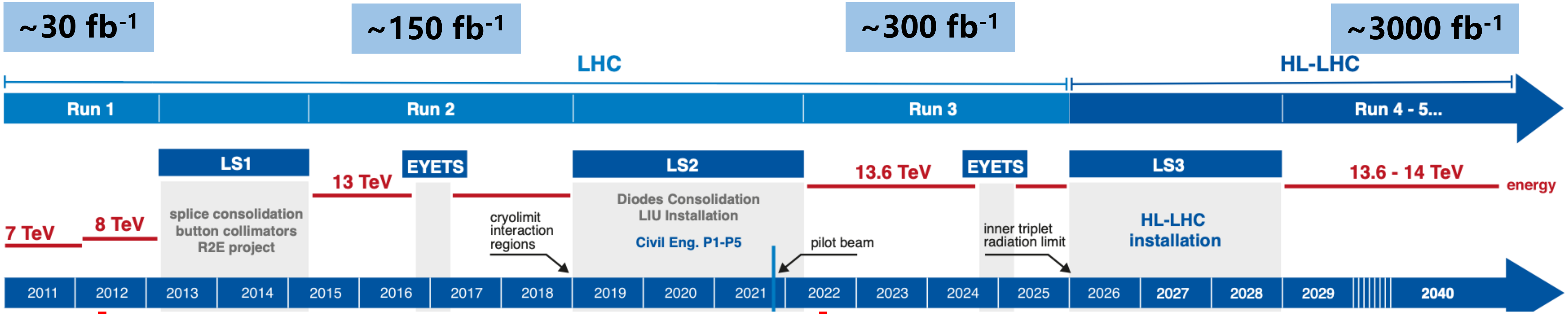
2013：Nobel Prize in Physics



Higgs Property Measurement

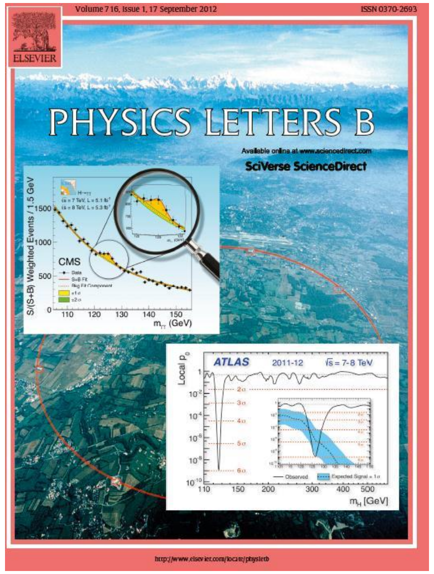
Nature 607, 52-59 (2022)
Nature 607, 60-68 (2022)

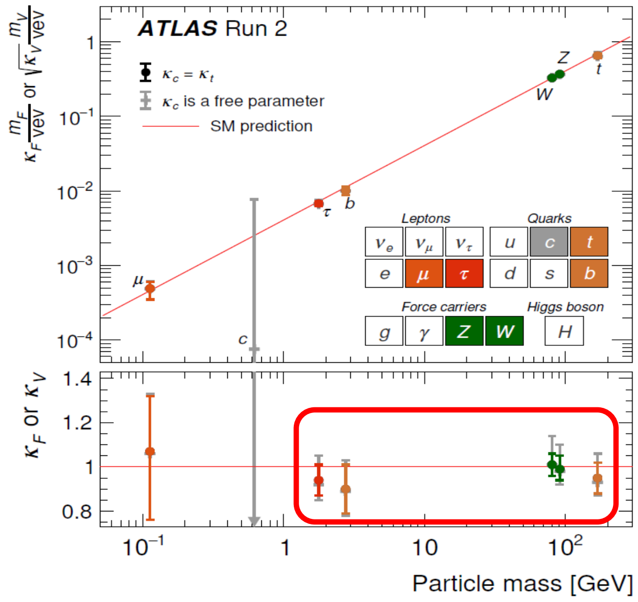
Higgs discovery to precision measurements



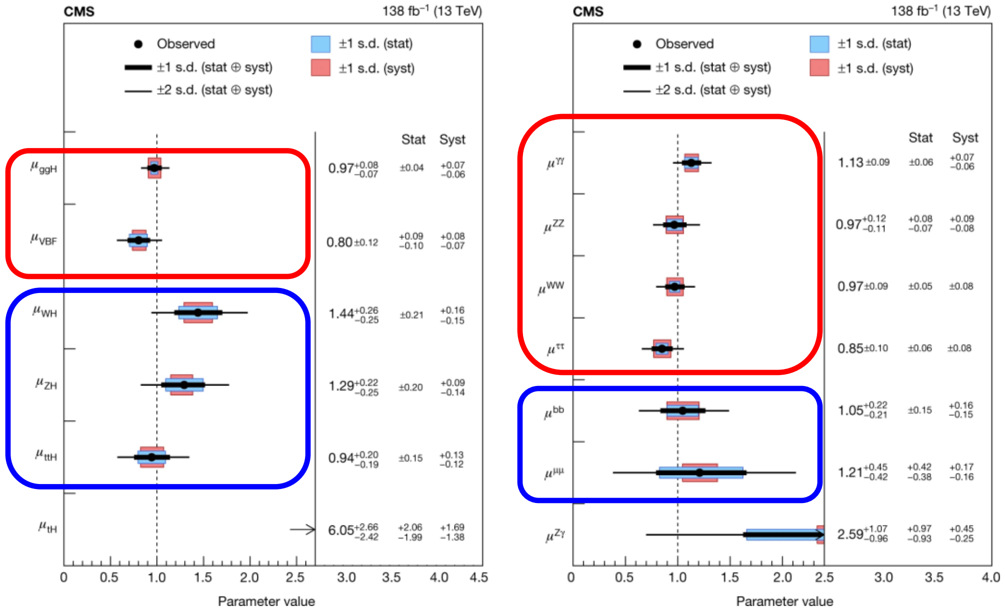
New milestone after 10 years of the Higgs discovery

Higgs Discovery





Nature 607 (2022) 52-59



5-10%

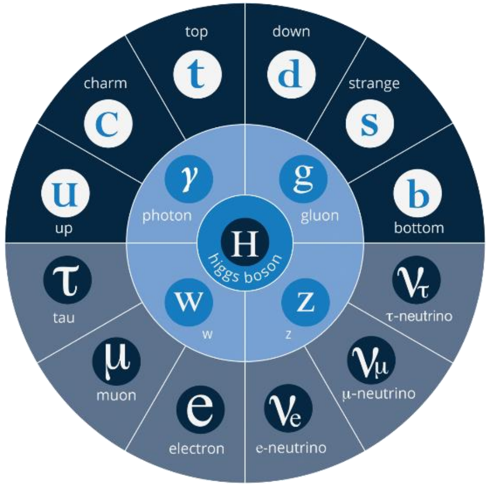
20-40%

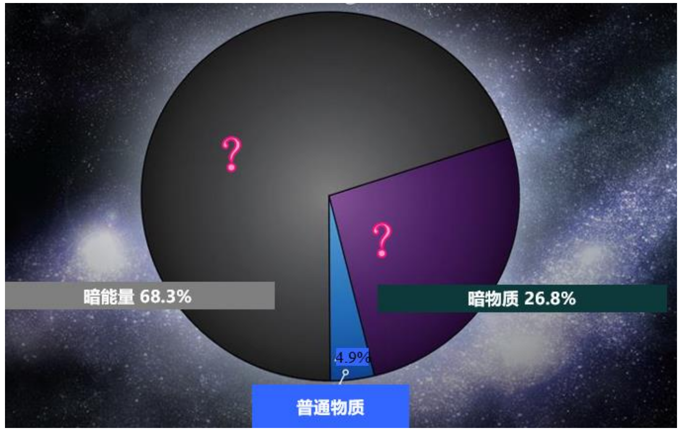
Nature 607 (2022) 60-68

Particle Physics after the Higgs Discovery

SM is a complete and self-consistent theory after the Higgs discovery.

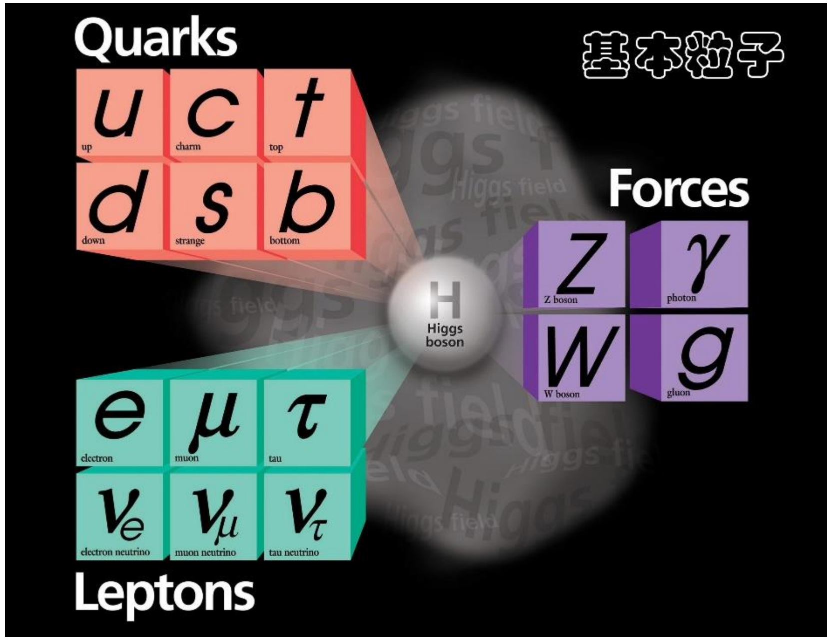
But it doesn't accommodate dark matter and dark energy → New physics ?

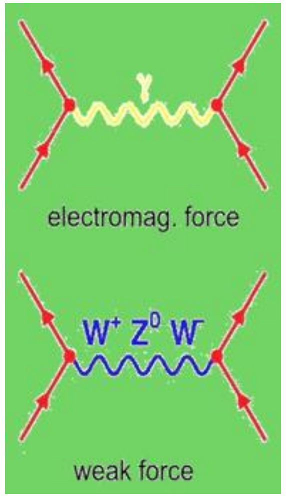




Dark matter and dark energy ~ 95%

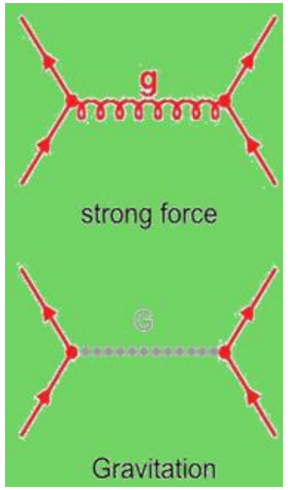
Higgs boson: a new force carrier





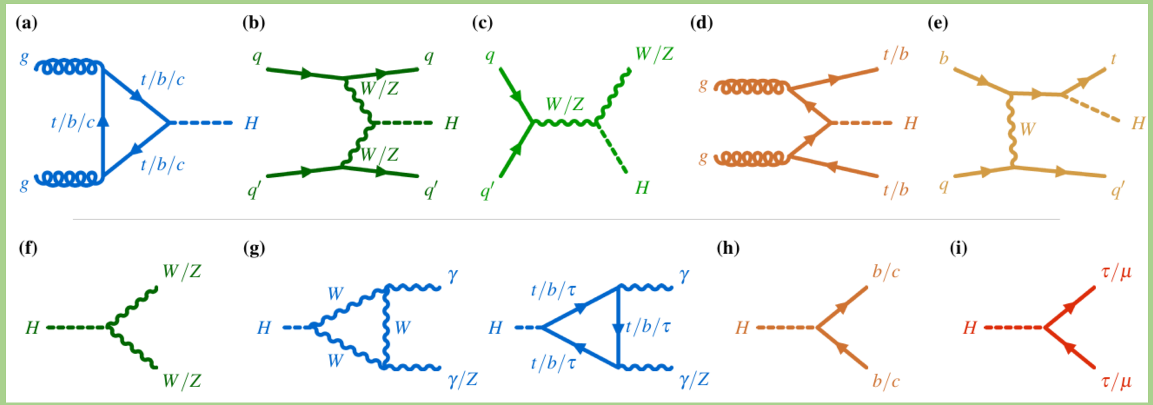
EM force: **Photon spin=1**

Weak force: **W/Z spin=1**



Strong force: **Gluon spin=1**

Gravity: **Graviton spin=2**

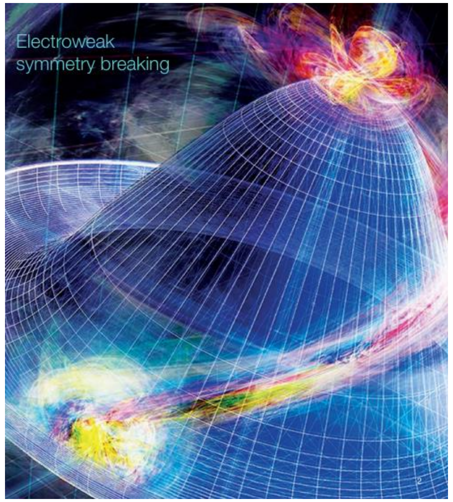


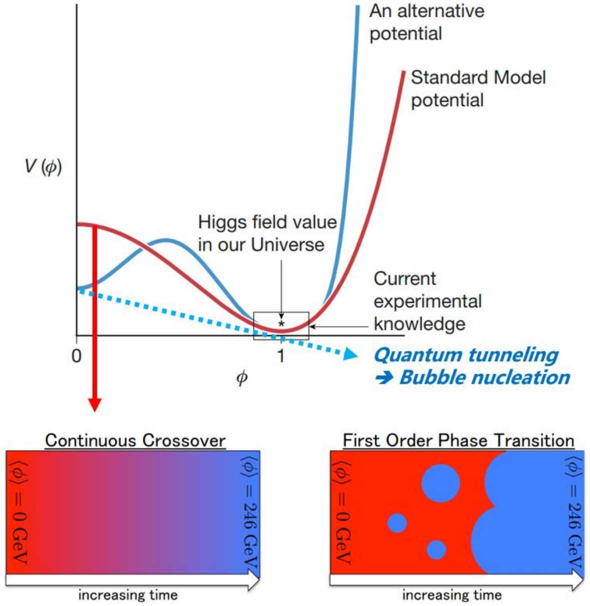
Higgs boson:

- Explains mass origin
- Only SM particle with spin 0
- A new force carrier

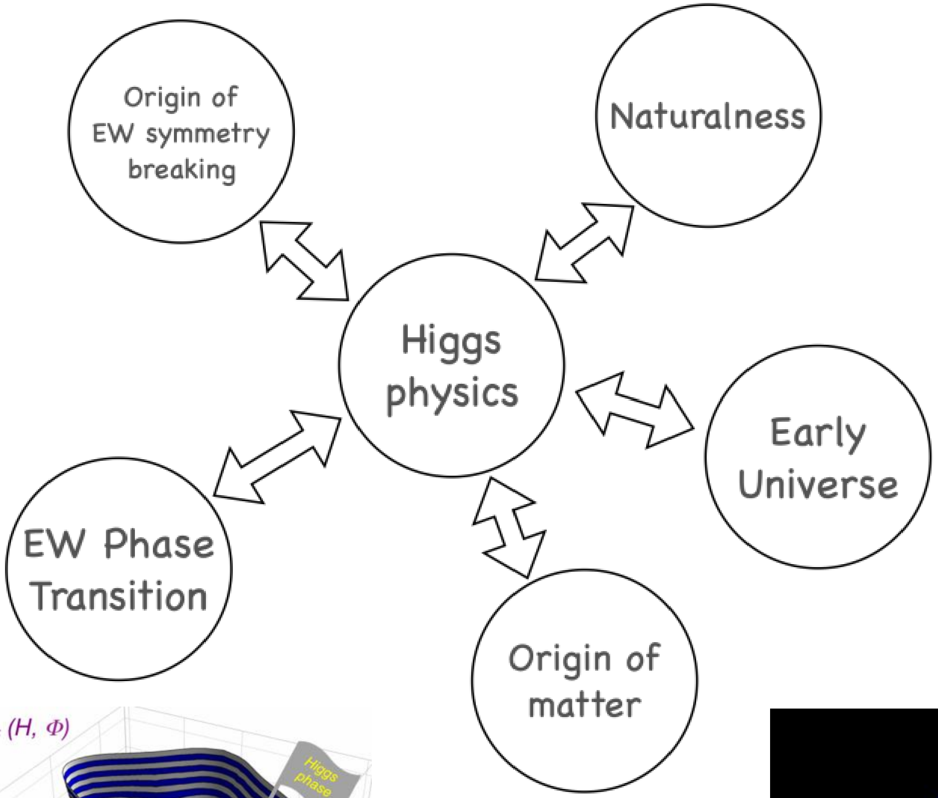
Higgs boson: a portal to new physics

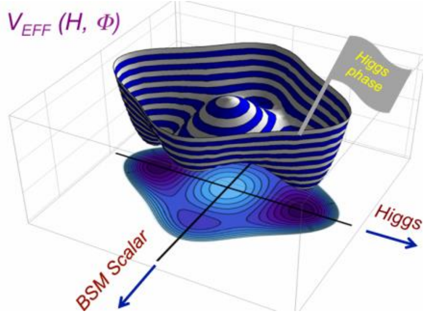
➔ EW symmetry breaking



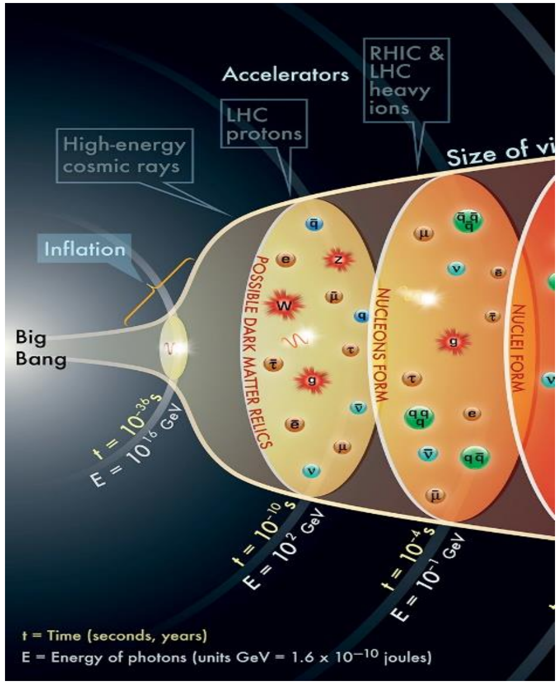


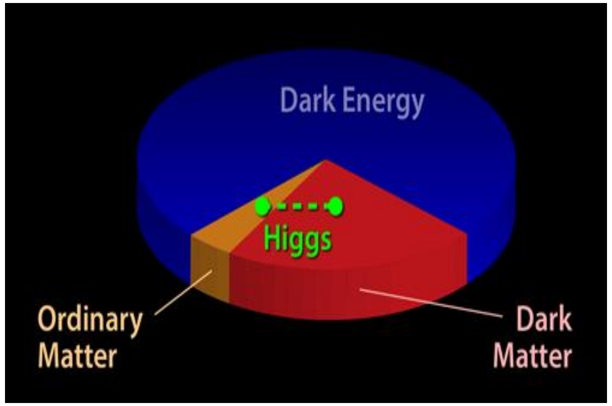
➔ Naturalness





➔ Early Universe





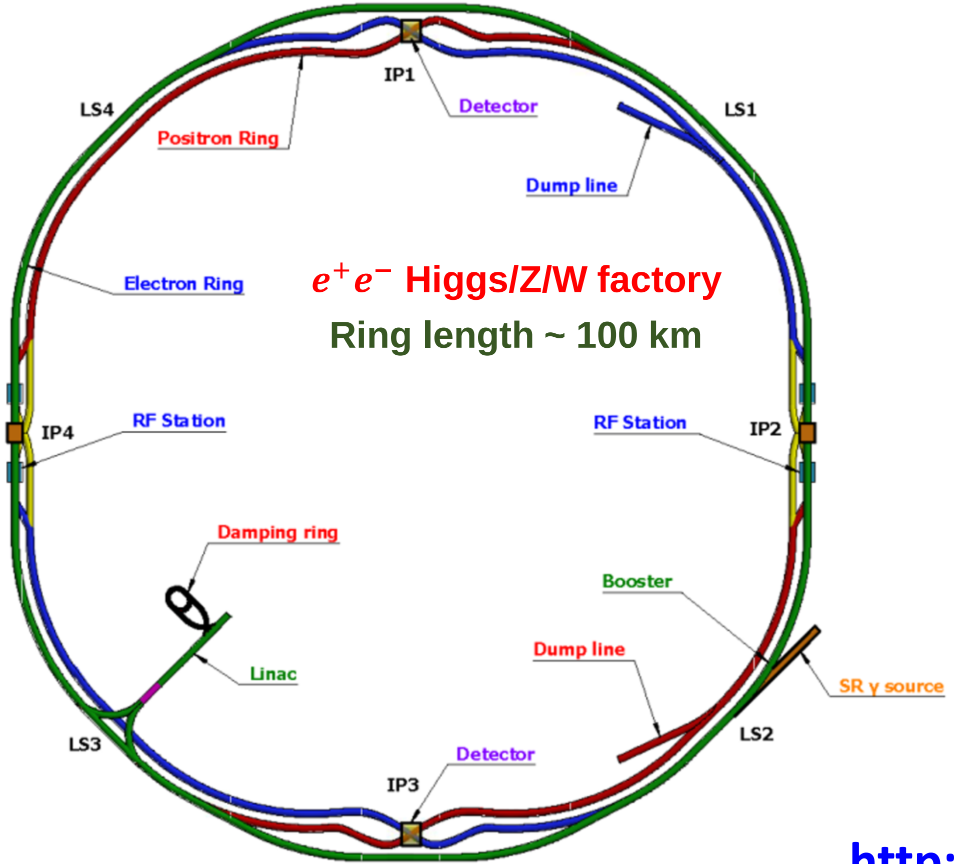
➔ EW Phase Transition

➔ Origin of matter

➔ Higgs portal to DM

Circular Electron Positron Collider (CEPC)

- The CEPC was proposed by the Chinese HEP community in 2012 right after the Higgs discovery. It aims to start operation in 2030s, as a Higgs / Z / W factory.
- To produce Higgs / W / Z / top for high precision Higgs, EW measurements, studies of flavor physics & QCD, and probes of new physics beyond the SM.
- It is possible to upgrade to a *pp* collider (SppC) of $\sqrt{s}$ ~ 100 TeV in the future.



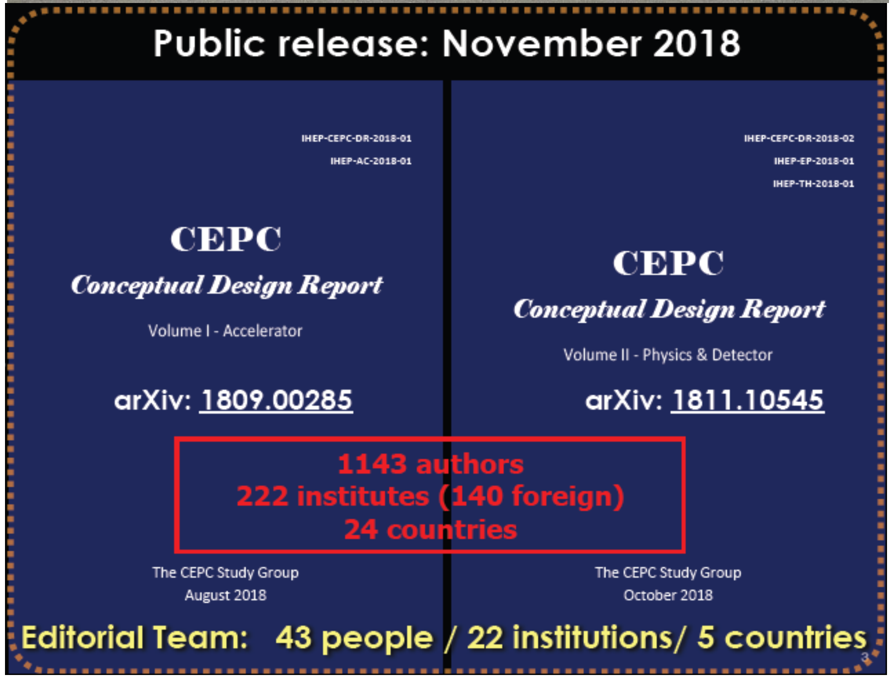
http://cepc.ihep.ac.cn/

CEPC Major Milestones

CEPC-SPPC Kickoff (2013.9)

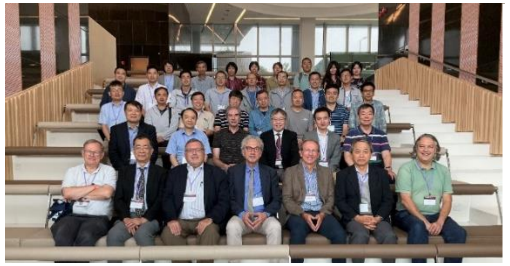
First CEPC IAC Meeting (2015.9)

CEPC CDR Released (2018.11)

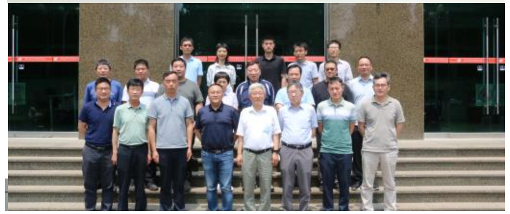


CEPC Major Milestones

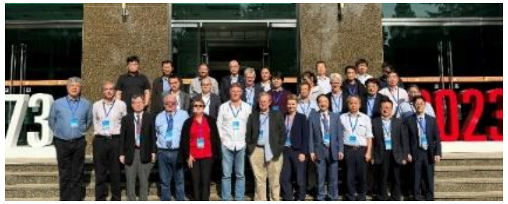
CEPC Accelerator TDR Review
June 12-16, 2023, Hong Kong



CEPC Accelerator TDR Cost Review
Sept. 11-15, 2023, Hong Kong

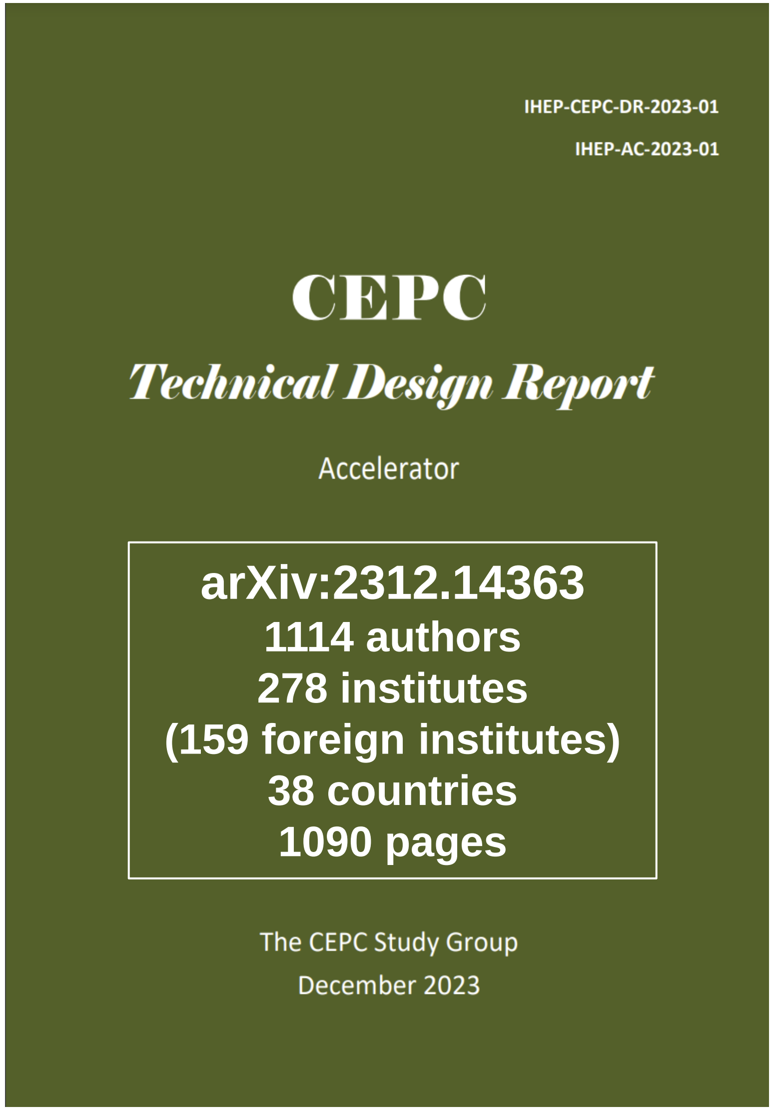


Domestic Civil Engineering
Cost Review, June 26, 2023, IHEP



9th CEPC IAC 2023 Meeting
Oct. 30-31, 2023, IHEP

CEPC Accelerator TDR released in December, 2023



IHEP-CEPC-DR-2023-01

IHEP-AC-2023-01

CEPC

Technical Design Report

Accelerator

arXiv:2312.14363
1114 authors
278 institutes
(159 foreign institutes)
38 countries
1090 pages

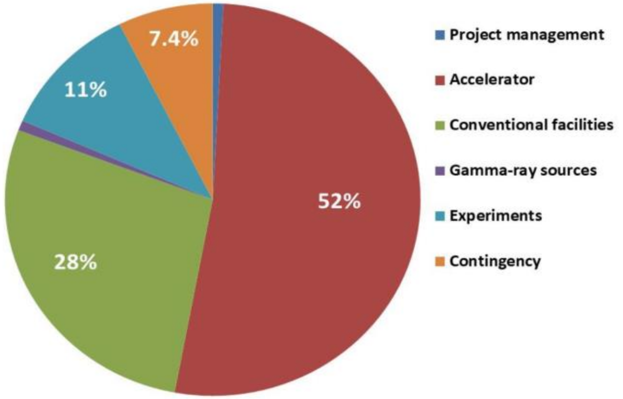
The CEPC Study Group

December 2023

Distribution of CEPC Project **TDR cost** of **36.4B RMB (~4.6B Euro)**

Table 12.1.2: CEPC project cost breakdown, (Unit: 100,000,000 yuan)

Total	**364**	**100%**
Project management	3	0.8%
Accelerator	190	52%
Conventional facilities	101	28%
Gamma-ray beam lines	3	0.8%
Experiments	40	11%
Contingency (8%)	27	7.4%



Global HEP Consensus on Higgs Factories

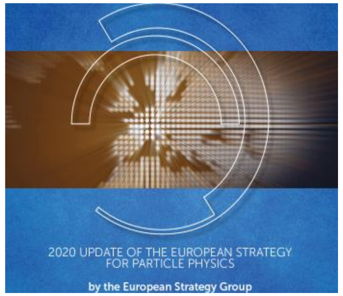
The scientific importance and strategical value of e^+e^- Higgs factories is clearly identified.

China

*2013, 2016: China Xiangshan Science Conference concluded that **CEPC is the best approach** and a major historical opportunity for the national development of accelerator-based high-energy physics program.*

JAHEP Japan

2017:** Japan Association of High Energy Physicists (JAHEP) proposes to construct **A 250 GeV center of mass ILC promptly as a Higgs factory.



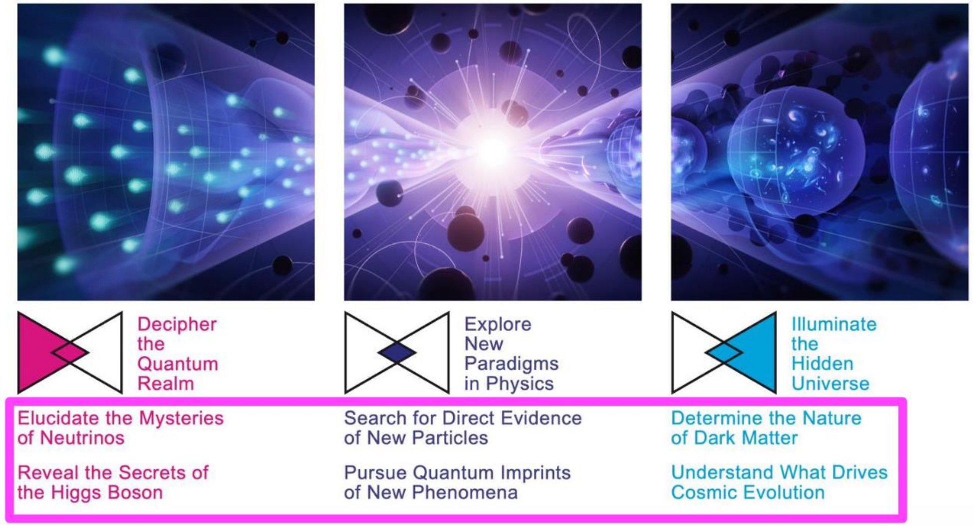
Europe

***2020:** European Strategy for Particle Physics, **An electron-positron Higgs factory is the highest priority next collider.** For the longer term, the European particle physics community has the ambition to operate a proton-proton collider at the highest achievable energy.*

ICFA

*2022, ICFA "reconfirmed the international consensus on the importance of **a Higgs factory as the highest priority for realizing the scientific goals of particle physics**", and expressed support for the above-mentioned Higgs factory proposals*

P5 report, USA, 2023



Exploring the Quantum Universe

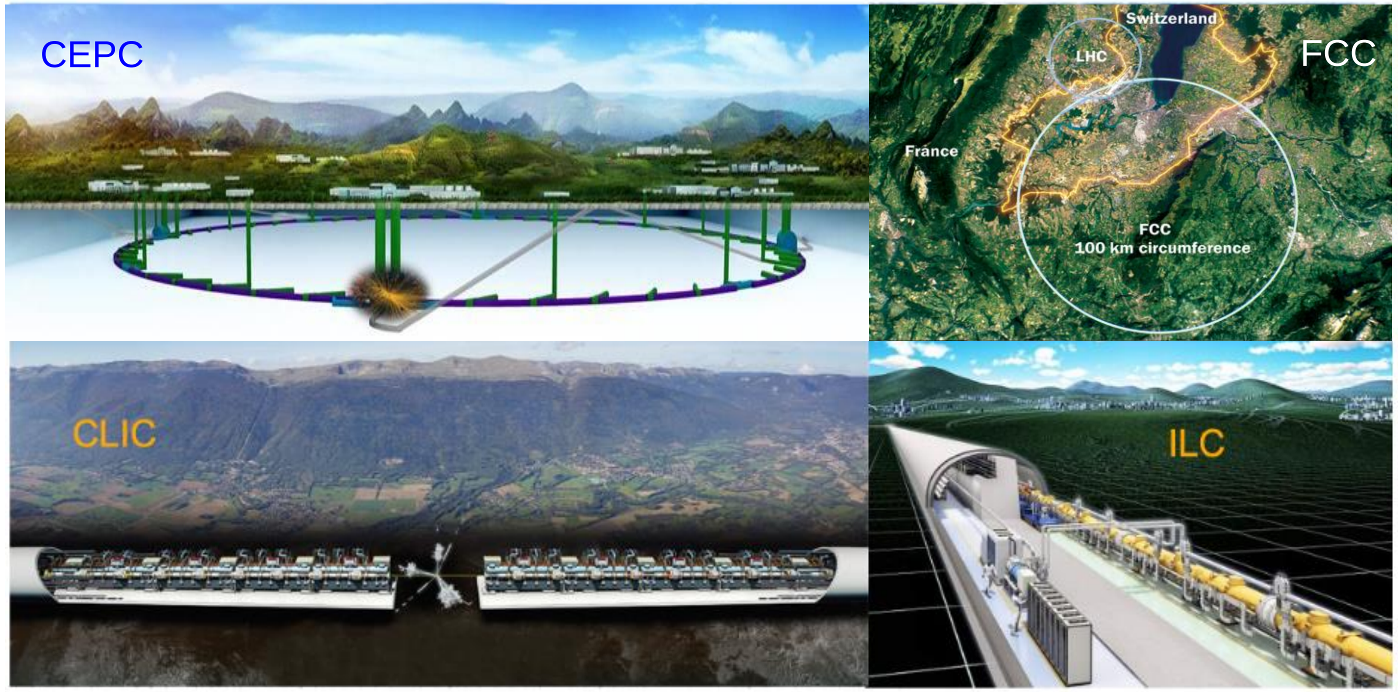
Recommendation 6

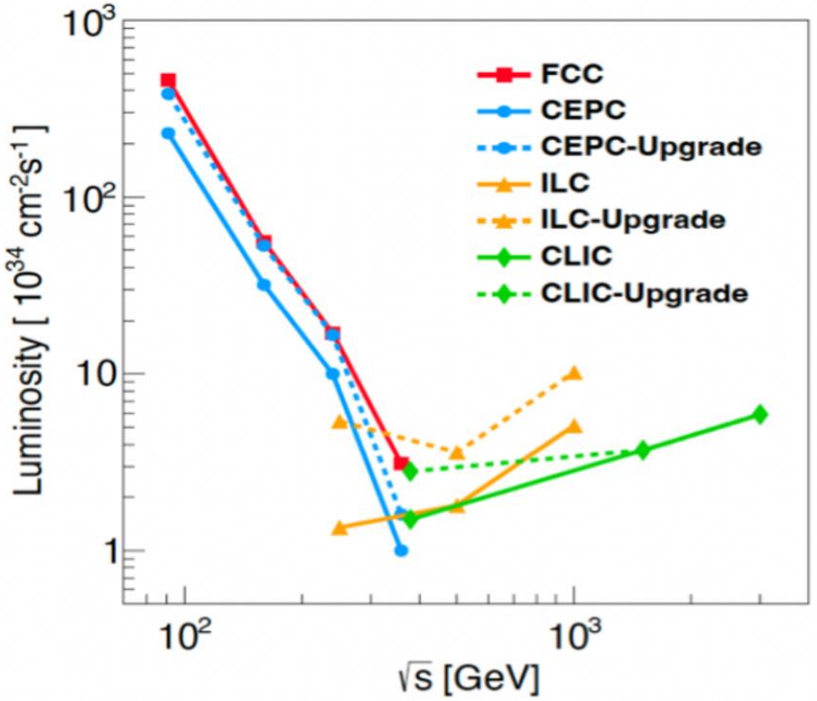
Convene a targeted panel with broad membership across particle physics later this decade that makes decisions on the US accelerator-based program at the time when major decisions concerning an off-shore Higgs factory are expected, and/or significant adjustments within the accelerator-based R&D portfolio are likely to be needed. A plan for the Fermilab accelerator complex consistent with the long-term vision in this report should also be reviewed.

The panel would consider the following:

1. The level and nature of US contribution in a specific Higgs factory including an evaluation of the associated schedule, budget, and risks once crucial information becomes available.
2. Mid- and large-scale test and demonstrator facilities in the accelerator and collider R&D portfolios.
3. A plan for the evolution of the Fermilab accelerator complex consistent with the longterm vision in this report, which may commence construction in the event of a more favorable budget situation.

Comparison of Higgs factories: Circular vs Linear





Luminosity per IP (10^{34} $cm^{-2}s^{-1}$)	Operation mode			
	H	Z	W	$t\bar{t}$
CEPC (TDR, 30 MW)	5	115	16	0.5
CEPC (TDR, 50 MW)	8.3	192	26.7	0.8
FCC-ee (FS MTR, 50 MW)	≥ 5.0	140	20	1.25

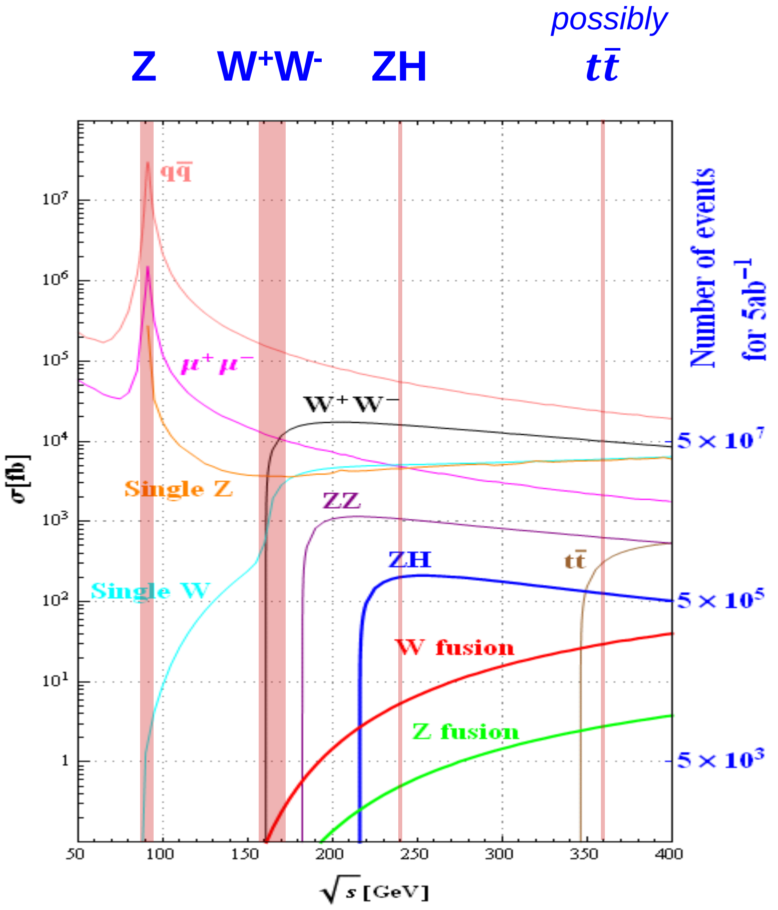
CEPC has strong advantages among mature e^+e^- Higgs factories (design report delivered)

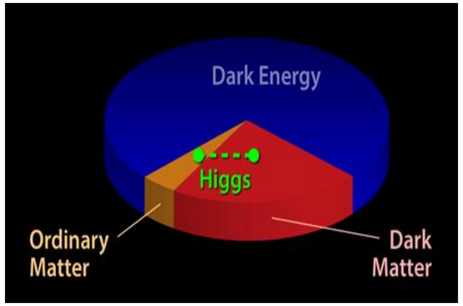
Versus FCC-ee
- Earlier data: collisions expected in 2030s (vs. ~ 2040s)
- Large tunnel cross section (ee & pp coexistence)
- Lower construction cost

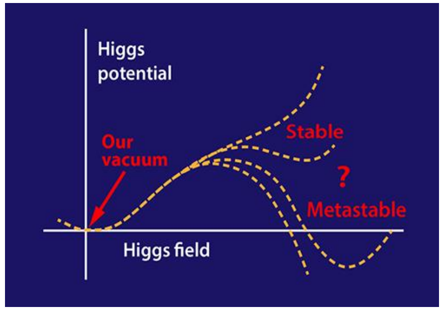
Versus Linear Colliders
- Higher luminosity / precision for Higgs & Z
- Potential upgrade for pp collider

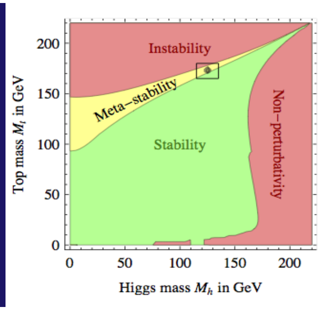
CEPC Physics Program

- **Measurements of Higgs, EW, flavor physics & QCD at unprecedented precision**
- **BSM physics (e.g. dark matter, EWPT, LLP, …) up to ~ 10 TeV scale**







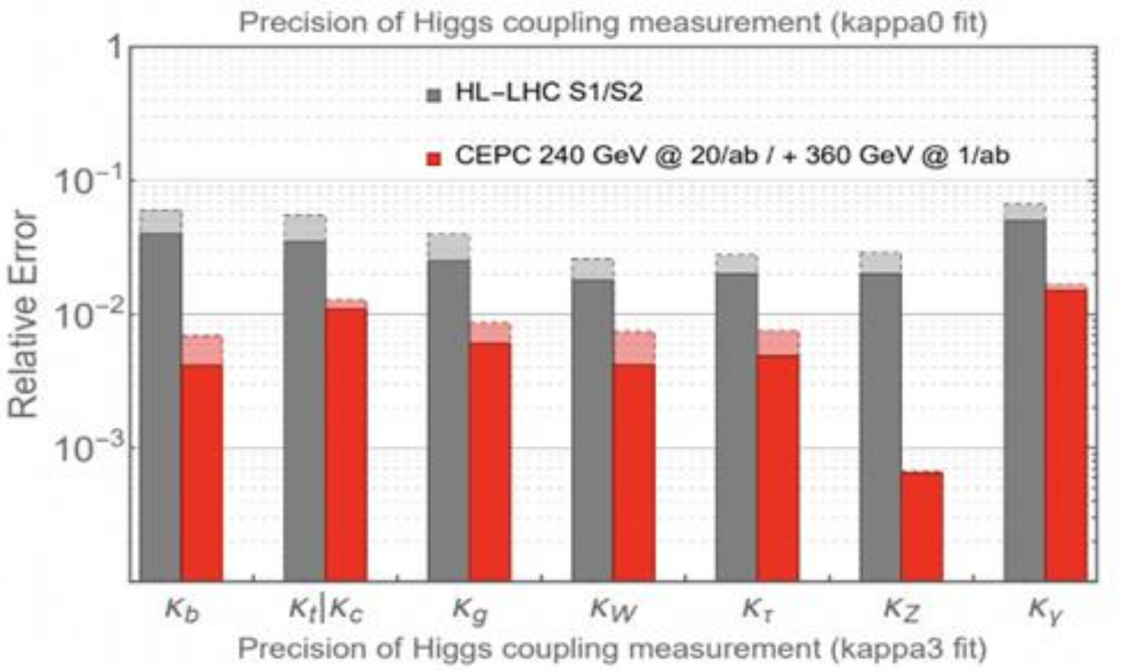


Operation mode		ZH	Z	W^+W^-	$t\bar{t}$
$\sqrt{s}$ [GeV]		~240	~91	~160	~360
Run Time [years]		10	2	1	~5
30 MW	L / IP [$\times10^{34}$ $cm^{-2}s^{-1}$]	**5.0**	**115**	**16**	**0.5**
	$\int L\,dt$ [ab^{-1}, 2 IPs]	13	60	4.2	0.6
	Event yields [2 IPs]	2.6×10^6	2.5×10^{12}	1.3×10^8	4×10^5
50 MW	L / IP [$\times10^{34}$ $cm^{-2}s^{-1}$]	**8.3**	**192**	**26.7**	**0.8**
	$\int L\,dt$ [ab^{-1}, 2 IPs]	22	100	6.9	1
	Event yields [2 IPs]	4.3×10^6	4.1×10^{12}	2.1×10^8	6×10^5

CEPC： Higgs Properties

➢ **CEPC has significantly better precision on Higgs properties than that of HL-LHC**

Higgs		
Observable	HL-LHC Projection	CEPC Precision
M_H	20 MeV	3 MeV
Γ_H	20%	1.7%
$\sigma\,(ZH)$	4.2%	0.26%
$B\,(H \rightarrow bb)$	4.4%	0.14%
$B\,(H \rightarrow cc)$	-	2.0%
$B\,(H \rightarrow gg)$	-	0.81%
$B\,(H \rightarrow WW)$	2.8%	0.53%
$B\,(H \rightarrow ZZ)$	2.9%	4.2%
$B\,(H \rightarrow \tau\tau)$	2.9%	0.42%
$B\,(H \rightarrow \gamma\gamma)$	2.6%	3.0%
$B\,(H \rightarrow \mu\mu)$	8.2%	6.4%
$B\,(H \rightarrow Z\gamma)$	20%	8.5%
$B_{upper}\,(H \rightarrow inv.)$	2.5%	0.07%



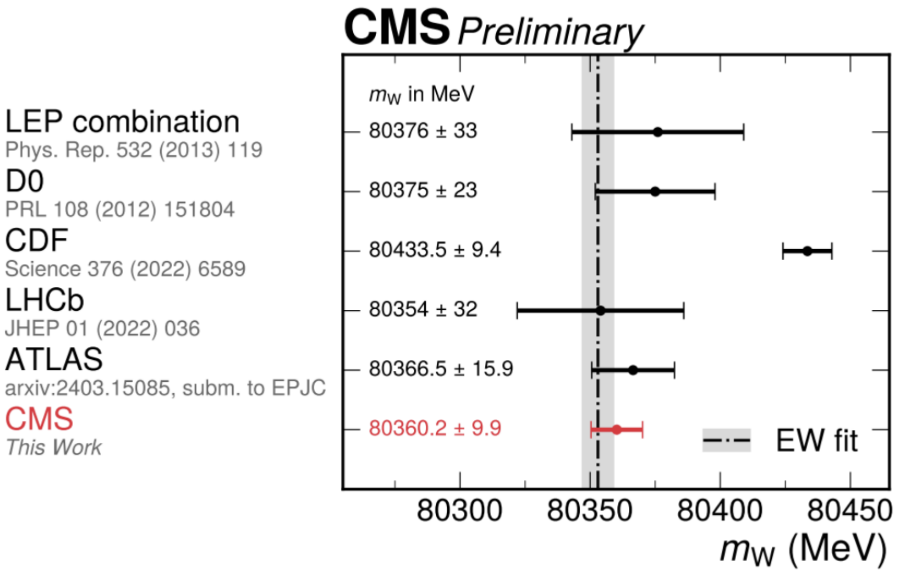
《Precision Higgs Physics at CEPC》
Chinese Physics C, 43 (2019) 043002

CEPC： Electroweak Measurements

➤ **CEPC has better EW precisions than current value by 1-2 order of magnitude**

W, Z and Top		
Observable	Current Precision	CEPC Precision
M_W	9 MeV	0.5 MeV
Γ_W	49 MeV	2 MeV
M_{top}	760 MeV	O(10) MeV
M_Z	2.1 MeV	0.1 MeV
Γ_Z	2.3 MeV	0.025 MeV
R_b	3×10^{-3}	2×10^{-4}
R_c	1.7×10^{-2}	1×10^{-3}
R_μ	2×10^{-3}	1×10^{-4}
R_τ	1.7×10^{-2}	1×10^{-4}
A_μ	1.5×10^{-2}	3.5×10^{-5}
A_τ	4.3×10^{-3}	7.0×10^{-5}
A_b	2×10^{-2}	2×10^{-4}
N_ν	2.5×10^{-3}	2×10^{-4}

CDF (2022) : 80433.5 ± 9.4 MeV
CMS(2024) : 80360.2 ± 9.9 MeV
SM Prediction : 80354 ± 7 MeV



➤ **CEPC: expected W mass resolution < 1MeV**

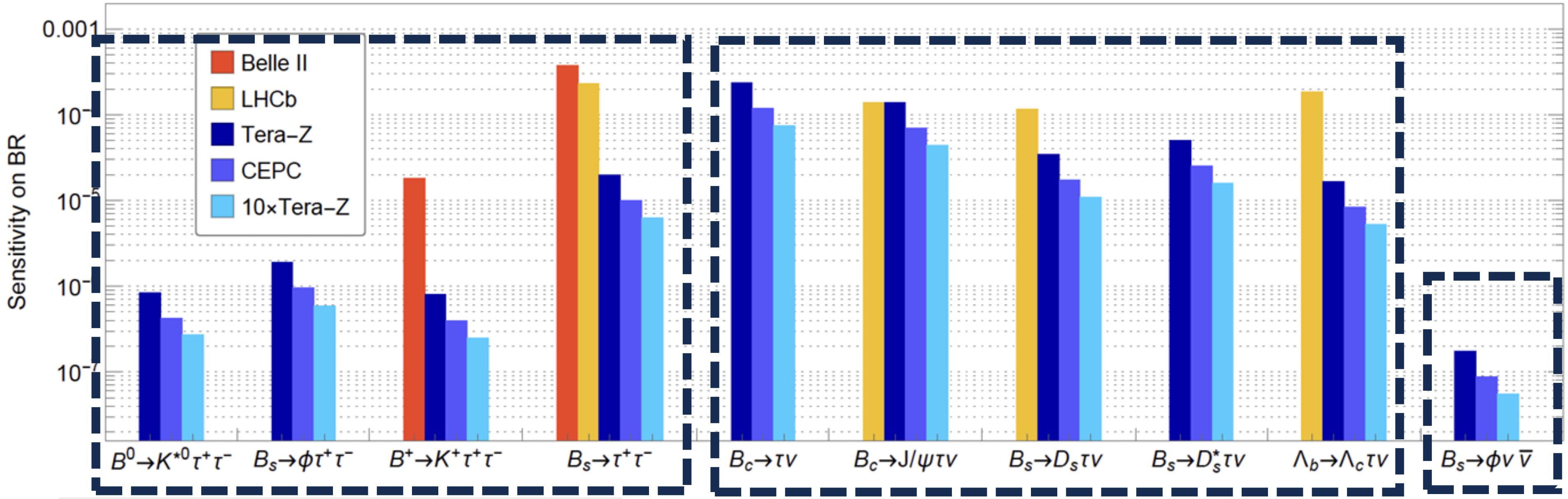
CEPC: Flavor Physics

Tera-Z → B factory

Mode	LEP bound (95% CL)	LHC bound (95% CL)	CEPC/FCC-ee
$\mathrm{BR}(Z \to \mu e)$	1.7×10^{-6} [2]	7.5×10^{-7} [3]	$10^{-8} - 10^{-10}$
$\mathrm{BR}(Z \to \tau e)$	9.8×10^{-6} [2]	5.0×10^{-6} [4, 5]	10^{-9}
$\mathrm{BR}(Z \to \tau \mu)$	1.2×10^{-5} [6]	6.5×10^{-6} [4, 5]	10^{-9}

Lepton Flavor Violation (FLV)

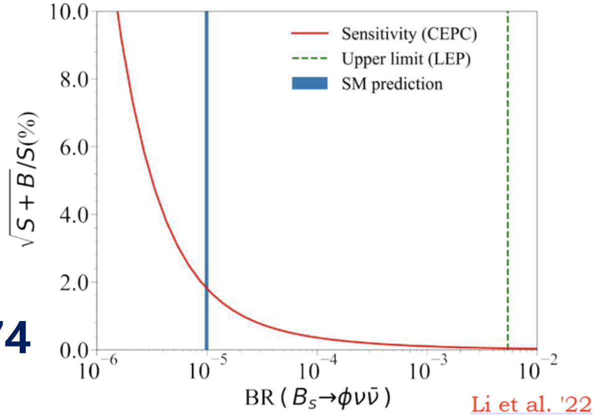
b-hadrons	Belle II (50+5 ab^{-1})	LHCb (300 fb^{-1})	Tera-Z
B^0, $\bar{B}^0$	5.4×10^{10} (50 ab^{-1} on $\Upsilon(4S)$)	3×10^{13}	1.2×10^{11}
$B^\pm$	5.7×10^{10} (50 ab^{-1} on $\Upsilon(4S)$)	3×10^{13}	1.2×10^{11}
B_s^0, $\bar{B}_s^0$	6.0×10^{8} (5 ab^{-1} on $\Upsilon(5S)$)	1×10^{13}	3.1×10^{10}
$B_c^\pm$	-	1×10^{11}	1.8×10^{8}
Λ_b^0, $\bar{\Lambda}_b^0$	-	2×10^{13}	2.5×10^{10}
$c(\bar{c})$	2.6×10^{11}	$\gtrsim 10^{14}$	2.4×10^{11}
$\tau^\pm$	9×10^{10}	-	7.4×10^{10}



Lepton Flavor Universality ($B \to s\,\tau\tau$)

Lepton Flavor Universality ($B_c \to \tau\nu$)

BR ($B_s \to \phi\nu\nu$) precision is ~2% in SM, it can make indirect constraint on B anomaly !



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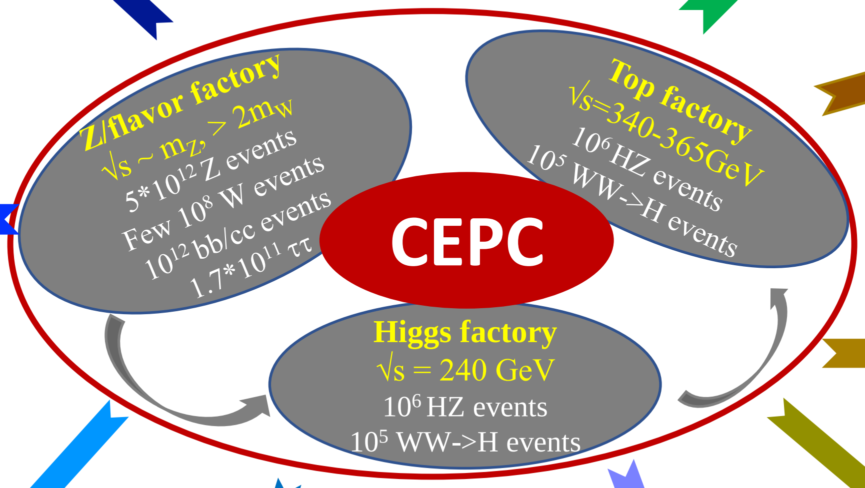
Li et al. '22

CEPC： BSM Physics



1: Exotics of Higgs, W, Z, top
- Higgs exotic decay (SUSY, LLP, DS, invisible)
- Light higgs
- Z exotic decay
- Top exotic decay

2: Dark Matter & Dark Sector
- SUSY DM
- Higgs portal DM
- Vector boson portal DM
- Fermion portal DM
- EFT
- ……

3: LLP
- At CEPC and FAR detector
- H/Z decay
- SUSY LLP
- VLL, ALP, …

4: SUSY
- Light EWKinos
- Light sleptons
- Heavy selectrons
- ……

5: Flavor portal NP
- cLFV processes
- Decays of b and c hadrons
- ……

6: EWPT & GW
- Probe nature EWPT
- Higgs precision
- Higgs exotic decay

7: Neutrino
- Heavy neutrinos
- Active-sterile neutrino
- Non-standard ν interactions

8: More exotics
- Axion-like particles
- Lepton form factors
- Emergent Hadron Mass
- Exotic lepton mass
- ……

9: Global fits
- Global fit of SUSY
- 2HDM global fit
- SMEFT global fit

10. Indirect searches from SM precision measurements

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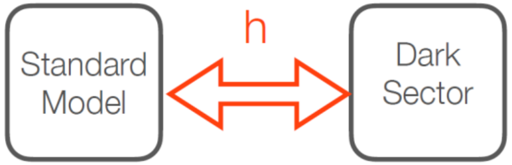
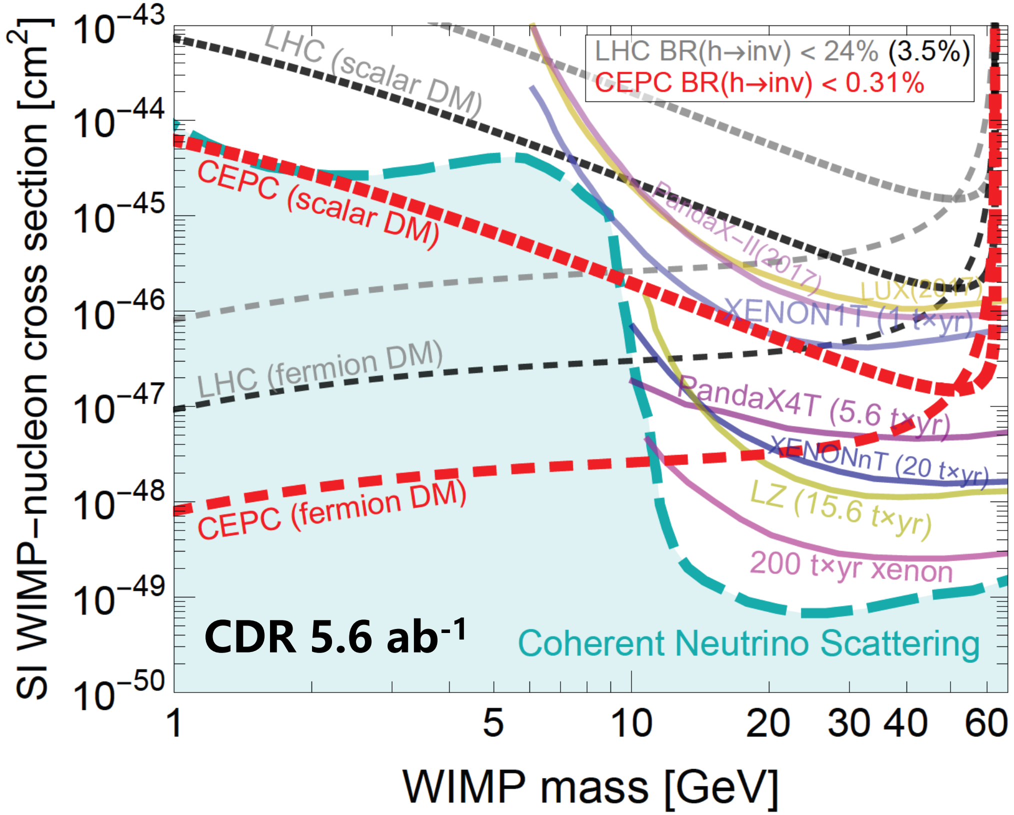
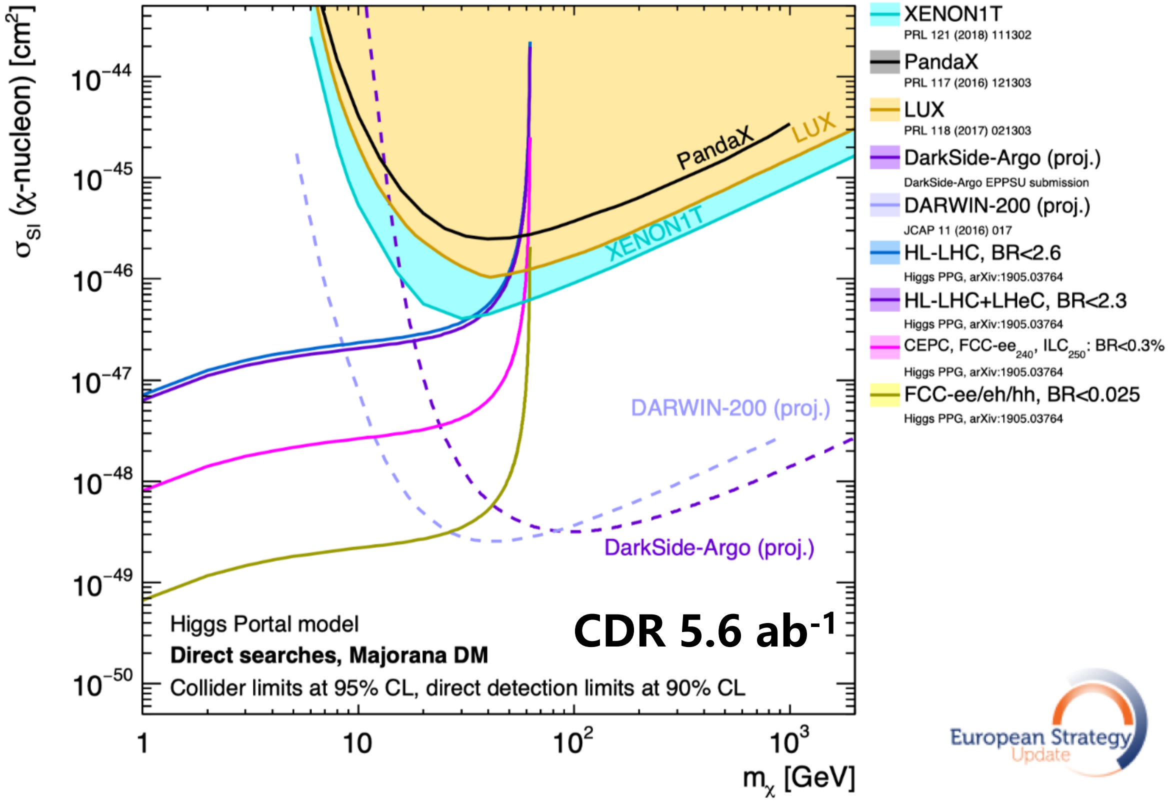
Higgs: Dark Matter Portal

Higgs-portal DM



$$h \to X_{\rm dm} X_{\rm dm}$$



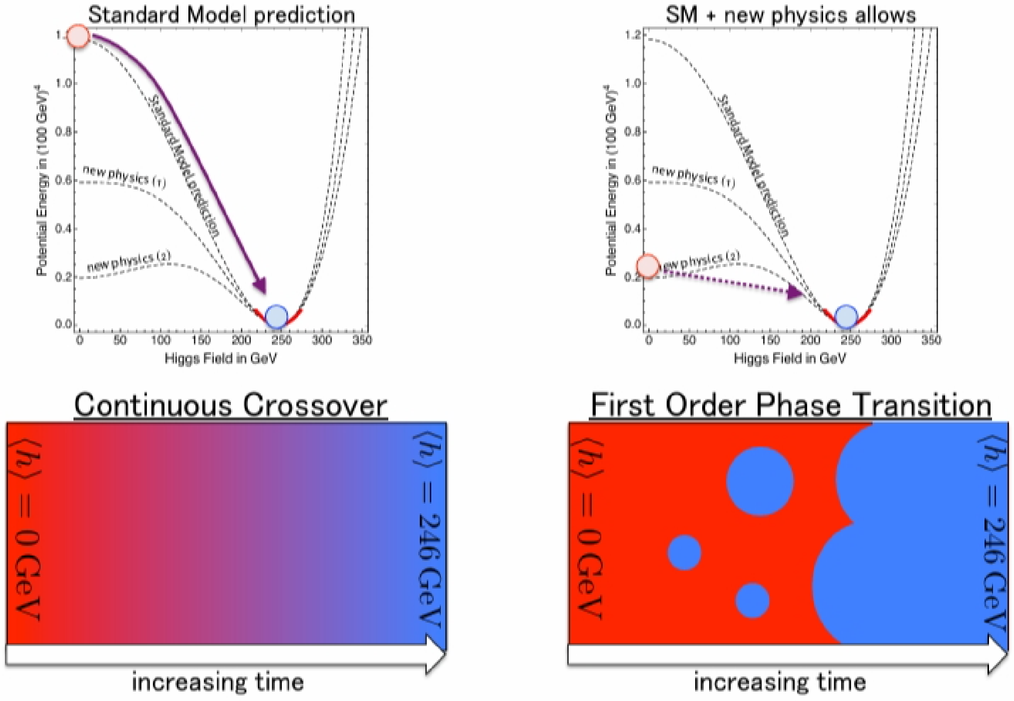


➔ **CEPC has significantly better detection sensitivity for DM than HL-LHC**

➔ **Complementary to direct DM search experiments for mass below 10 GeV**

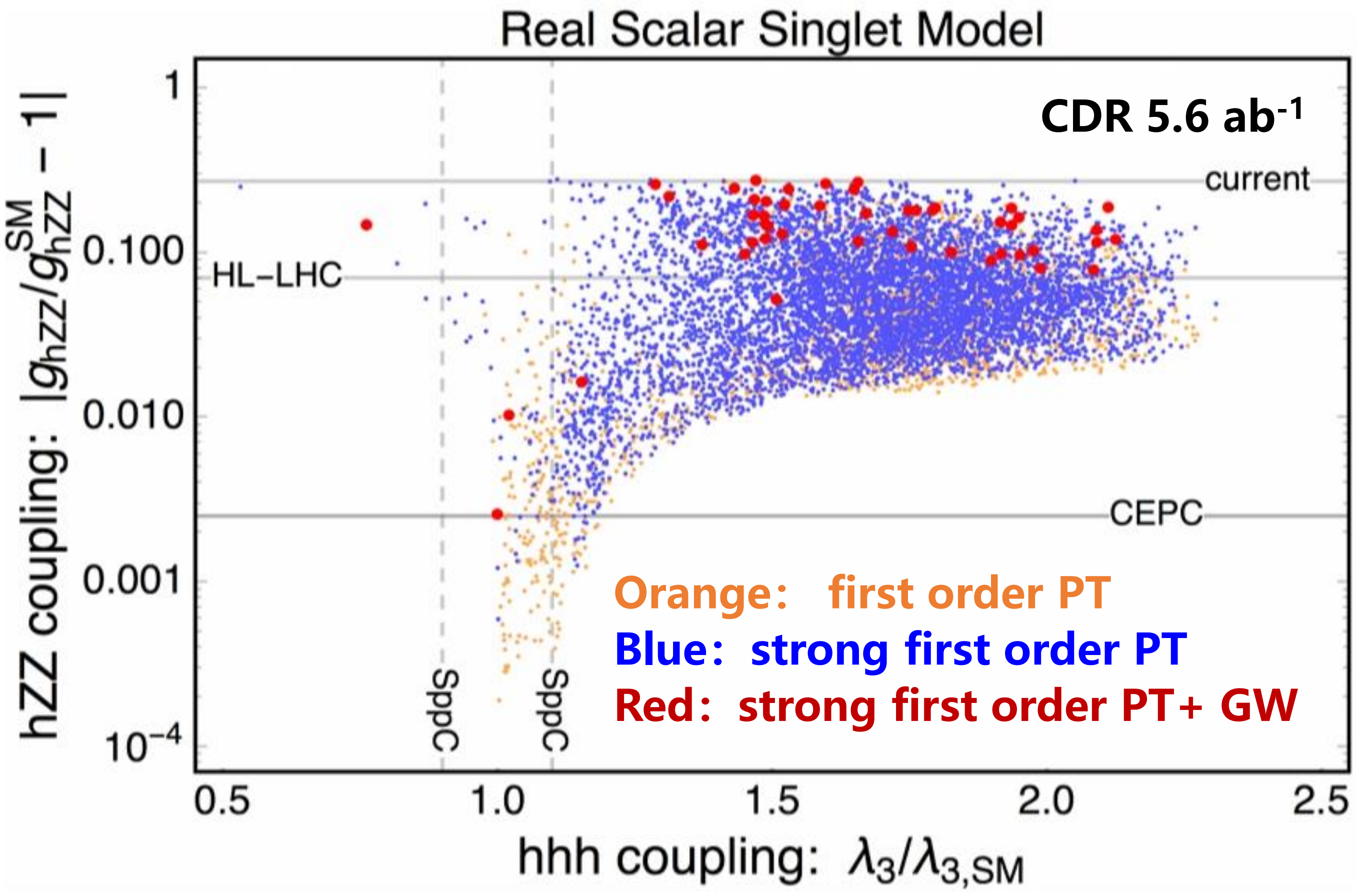
Higgs： EW Phase Transition

➔ CEPC can study EWPT via hZZ coupling measurement which may help to understand the matter-antimatter asymmetry, its detection sensitivity is about one order of magnitude better than that of the HL-LHC.



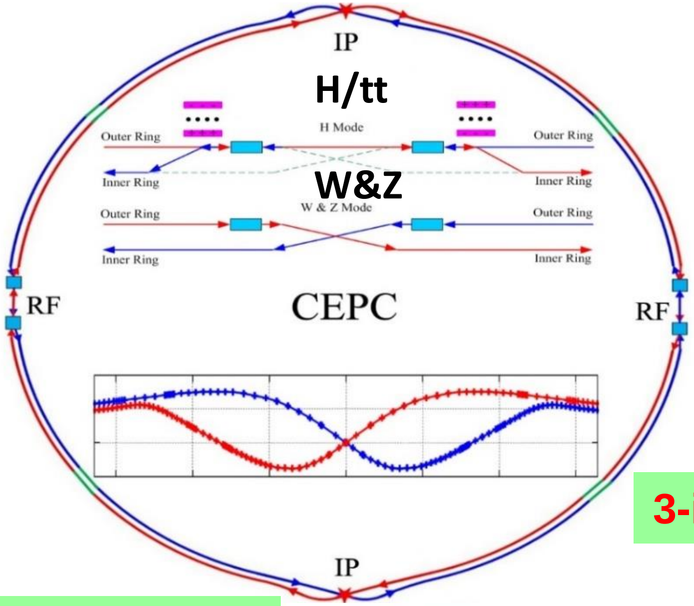
SM expects Higgs potential has smooth crossover

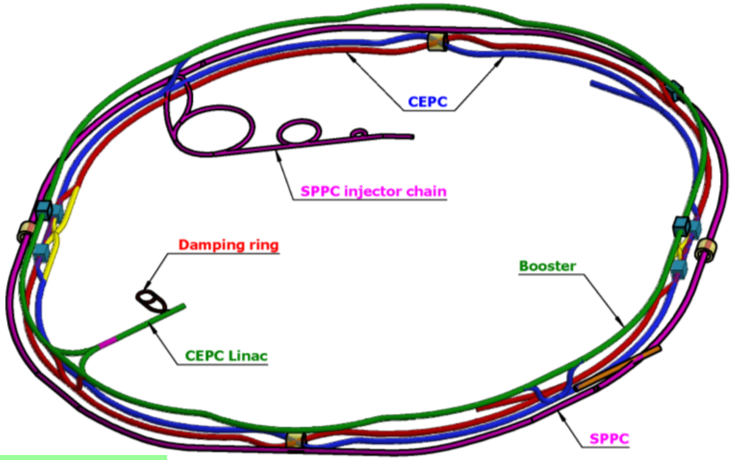
New Physics
Quantum tunneling
First order phase transition



CEPC Accelerator Design and Layout

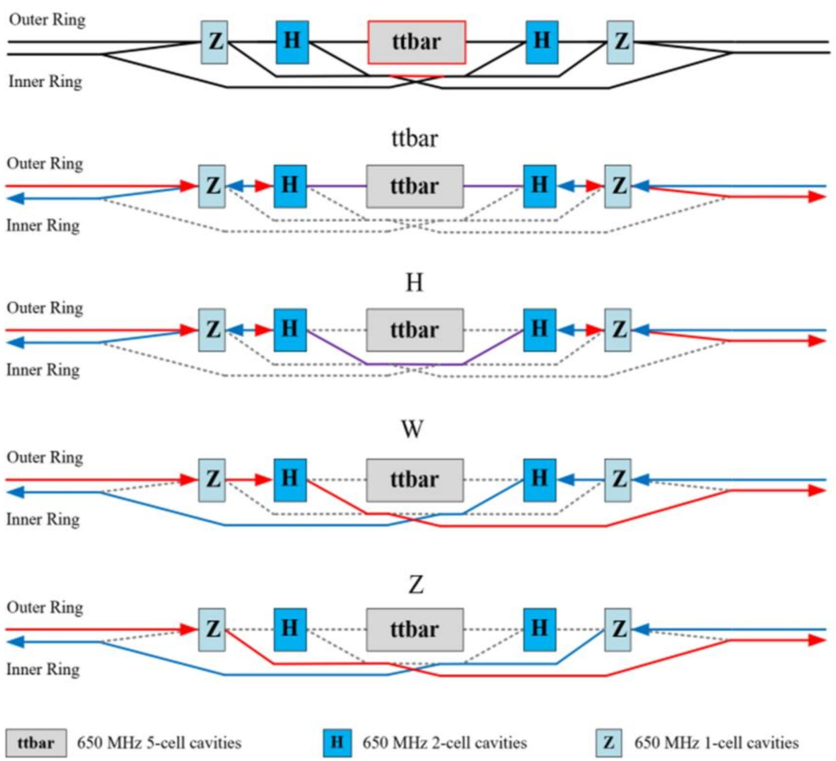
- 100 km double ring design (30 MW SR, upgradable to 50MW, ttbar)
- Switchable operation for H, Z, W and top modes (bypass scheme)
- Shared tunnel: compatible design for booster, CEPC and SppC



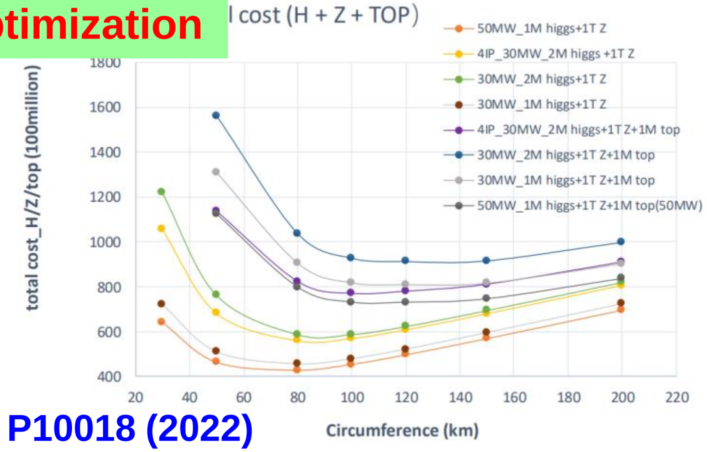


3-in-1 tunnel

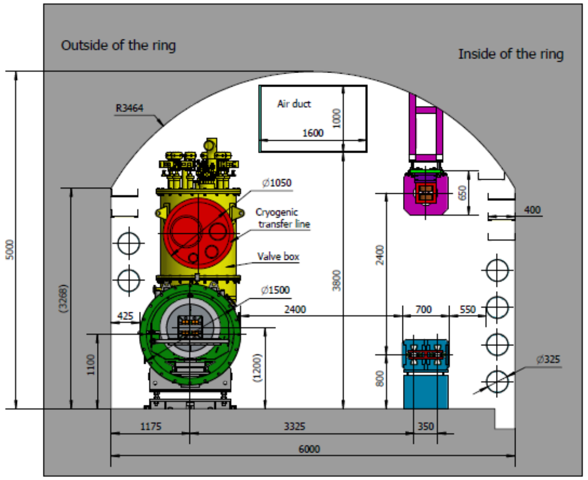
H/W/Z/tt switchable bypass scheme



Cost optimization



TUNNEL CROSS SECTION OF THE ARC AREA



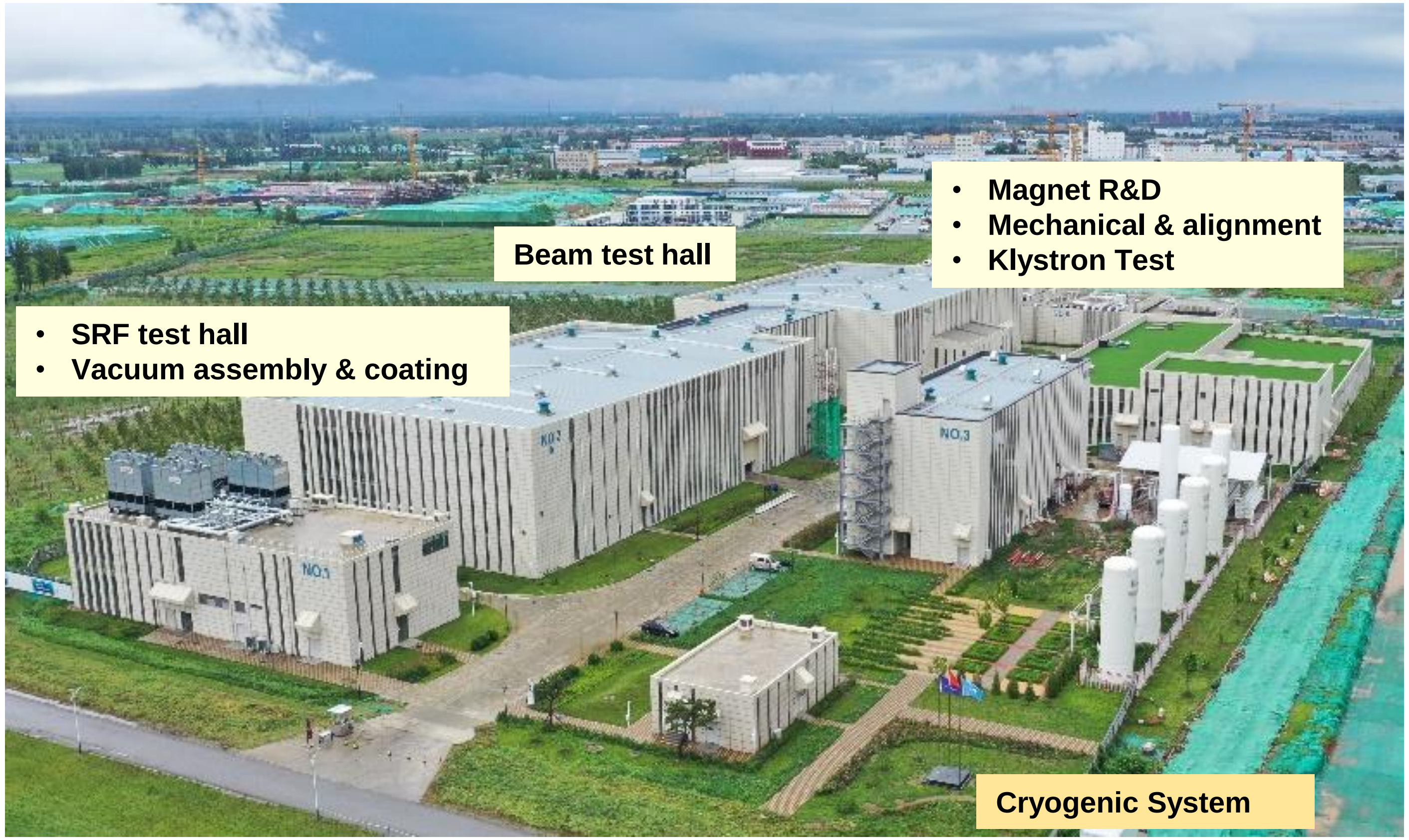
JINST 17 P10018 (2022)

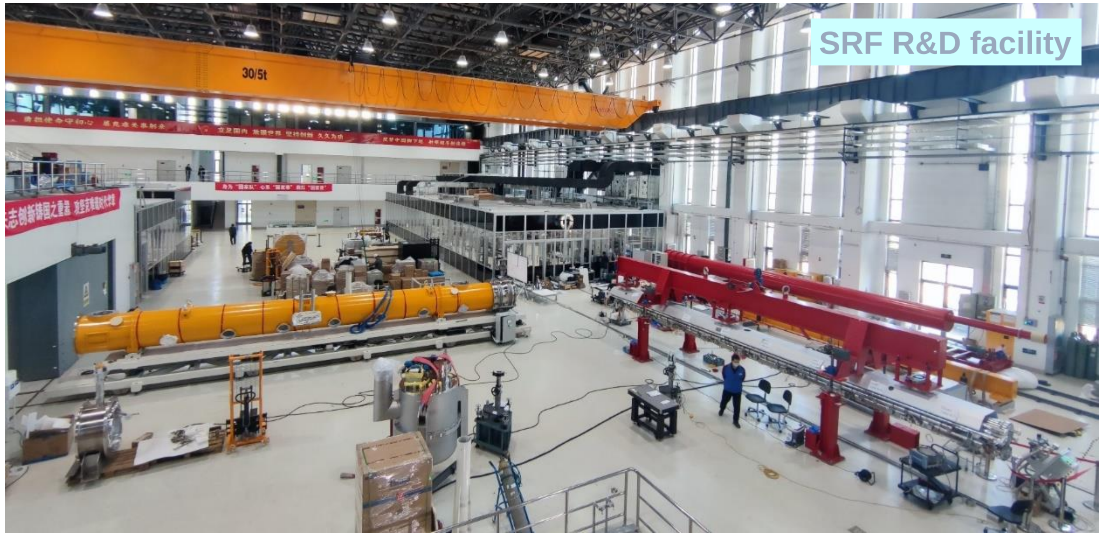
arXiv:2312.14363

CEPC Accelerator Parameters

	Higgs	Z	W	$t\bar{t}$
Number of IPs	2			
Circumference (km)	100.0			
SR power per beam (MW)	30			
Half crossing angle at IP (mrad)	16.5			
Bending radius (km)	10.7			
Energy (GeV)	120	45.5	80	180
Energy loss per turn (GeV)	1.8	0.037	0.357	9.1
Damping time $\tau_x/\tau_y/\tau_z$ (ms)	44.6/44.6/22.3	816/816/408	150/150/75	13.2/13.2/6.6
Piwinski angle	4.88	24.23	5.98	1.23
Bunch number	268	11934	1297	35
Bunch spacing (ns)	591 (53% gap)	23 (18% gap)	257	4524 (53% gap)
Bunch population (10^{11})	1.3	1.4	1.35	2.0
Beam current (mA)	16.7	803.5	84.1	3.3
Phase advance of arc FODO (°)	90	60	60	90
Momentum compaction (10^{-5})	0.71	1.43	1.43	0.71
Beta functions at IP β_x^*/β_y^* (m/mm)	0.3/1	0.13/0.9	0.21/1	1.04/2.7
Emittance $\varepsilon_x/\varepsilon_y$ (nm/pm)	0.64/1.3	0.27/1.4	0.87/1.7	1.4/4.7
Betatron tune n_x/n_y	445/445	317/317	317/317	445/445
Beam size at IP s_x/s_y (um/nm)	14/36	6/35	13/42	39/113
Bunch length (natural/total) (mm)	2.3/4.1	2.5/8.7	2.5/4.9	2.2/2.9
Energy spread (natural/total) (%)	0.10/0.17	0.04/0.13	0.07/0.14	0.15/0.20
Energy acceptance (DA/RF) (%)	1.6/2.2	1.0/1.7	1.2/2.5	2.0/2.6
Beam-beam parameters x_x/x_y	0.015/0.11	0.004/0.127	0.012/0.113	0.071/0.1
RF voltage (GV)	2.2	0.12	0.7	10
RF frequency (MHz)	650			
Longitudinal tune n_s	0.049	0.035	0.062	0.078
Beam lifetime (Bhabha/beamstrahlung) (min)	39/40	82/2800	60/700	81/23
Beam lifetime (min)	20	80	55	18
Hourglass Factor	0.9	0.97	0.9	0.89
Luminosity per IP (10^{34} cm^{-2} s^{-1})	5.0	115	16	0.5

CEPC Key Technology R&D Platform



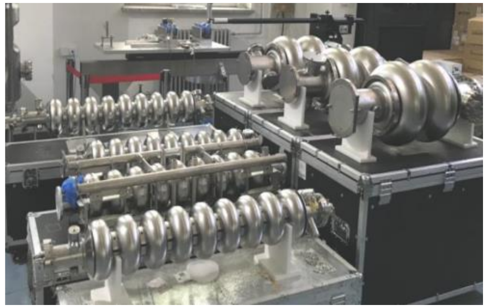


Accelerator key technology R&D platform was established:

- SRF cavity and module
- High precision magnet
- Vacuum assembly & coating
- High efficiency Klystron
- Mechanics and alignment
- Beam test facility

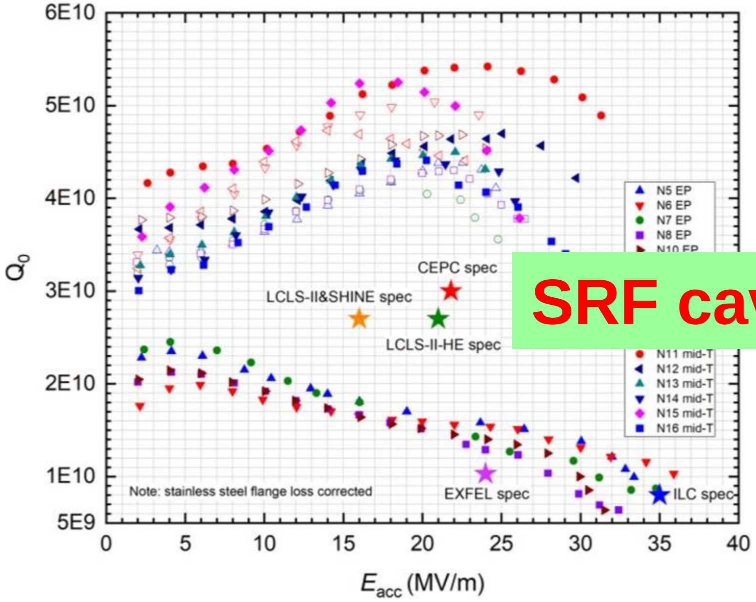
CEPC R&D: High Q SRF Cavities

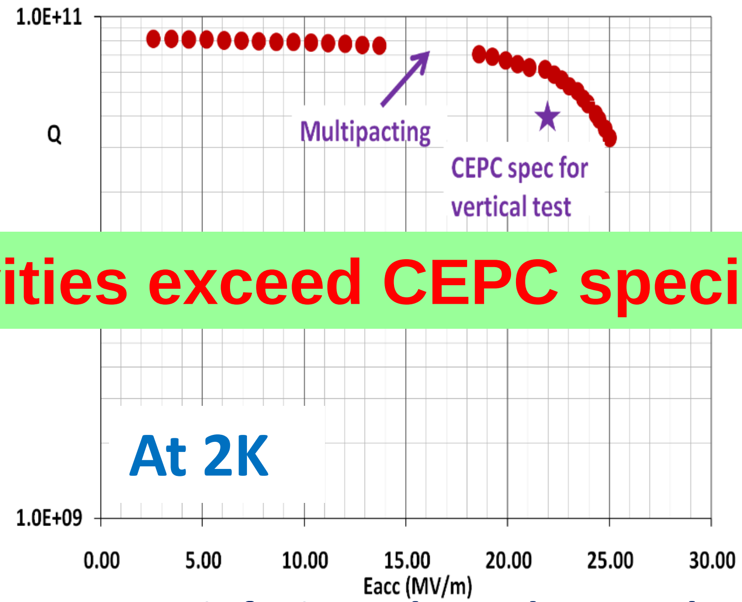
- 1.3 GHz 9-cell SRF cavity for booster: Q_0 = 3.4E10 @ 26.5 MV/m
- 650 MHz 2-cell SRF cavity for collider ring: Q_0 = 6.0E10 @ 22.0 MV/m
- 650 MHz 1-cell SRF cavity for collider ring: Q_0 = 6.0E10 @ 31.0 MV/m

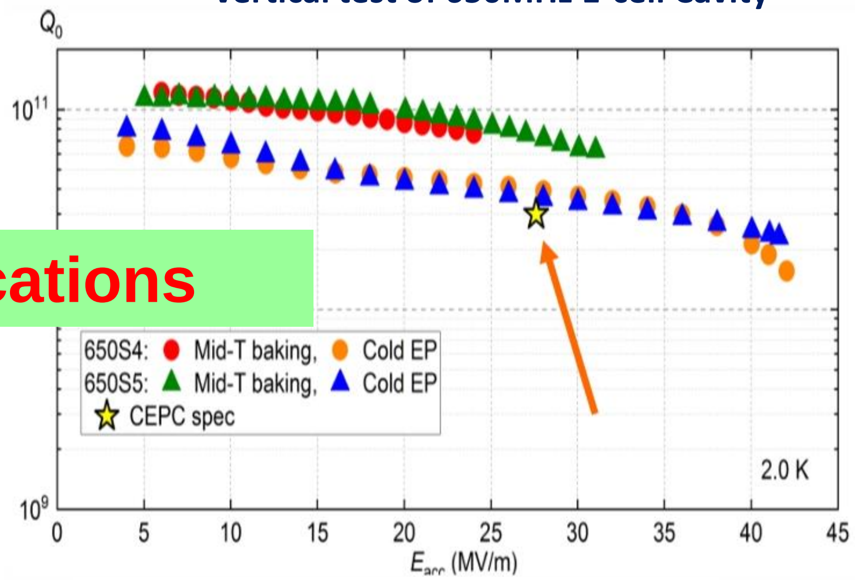


Vertical test of 650 MHz 2-cell cavity

Vertical test of 650MHz 1-cell Cavity







SRF cavities exceed CEPC specifications

Medium-temperature (Mid-T) annealing adopted to reach Q_0 = 3.4E10 @ 26.5 MV/m

N-infusion adopted to reach Q_0 = 6.0E10 @ 22.0 MV/m

Cold-EP and Mid-T baking Q_0 = 6.0E10 @ 31 MV/m

CEPC R&D: 8 × 9-cell High Q Cryomodule

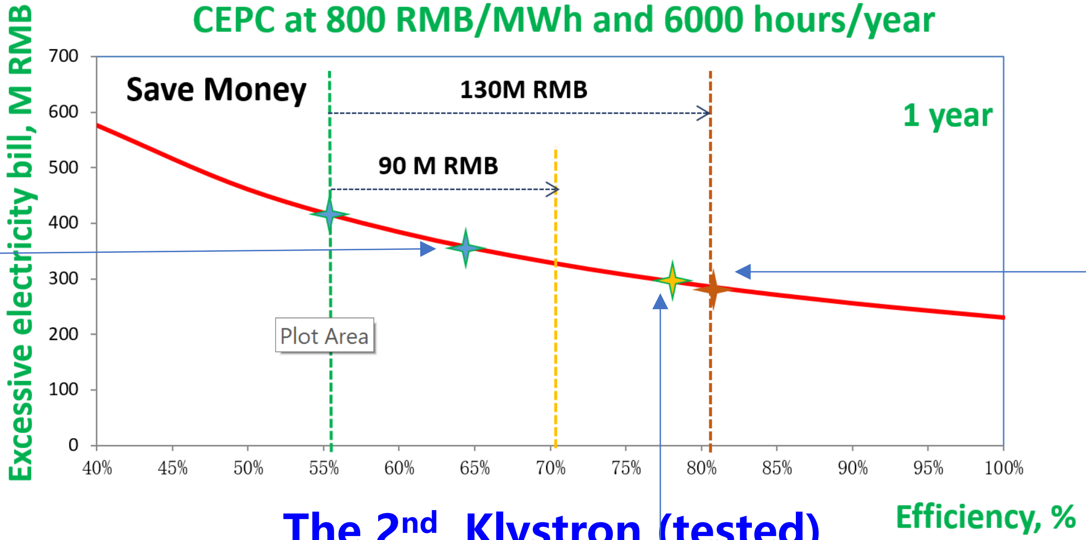
CEPC Booster 1.3 GHz SRF R&D and industrialization in synergy with CW FEL projects

Parameters	Horizontal test results	CEPC Booster Higgs Spec	LCLS-II, SHINE Spec	LCLS-II-HE Spec
Average usable CW E_{acc} (MV/m)	23.1	3.0×10^{10} @ 21.8 MV/m	2.7×10^{10} @ 16 MV/m	2.7×10^{10} @ 20.8 MV/m
Average Q_0 @ 21.8 MV/m	3.4×10^{10}			

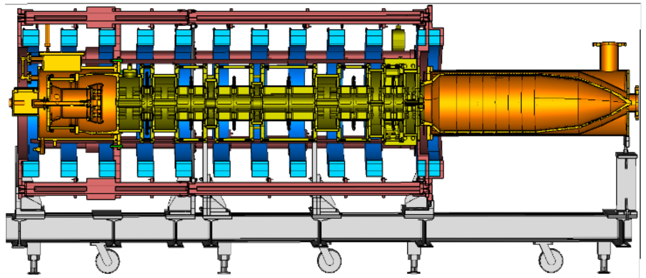
SRF cavities exceed CEPC specifications

CEPC R&D: High Efficiency Klystrons

- The 1st Klystron prototype, achieved efficiency ~ 62%
- The 2nd Klystron prototype was tested in Feb. 2024, achieved efficiency ~ 77.2%
- The 3rd Klystron prototype (MBK) with manufacture underway, design efficiency is ~ 80.5%
- High efficiency Klystron helps to reduce electricity consumption

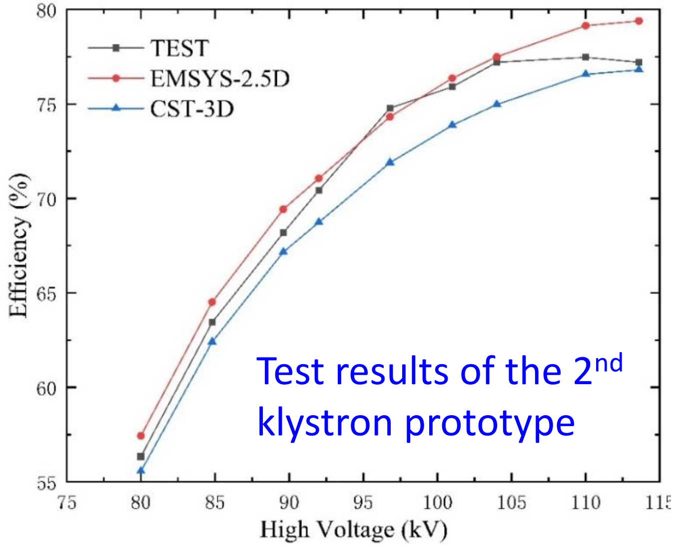


The 3rd multi-beam Klystron (MBK) under fabrication



The 1st Klystron (tested)

The 2nd Klystron (tested)

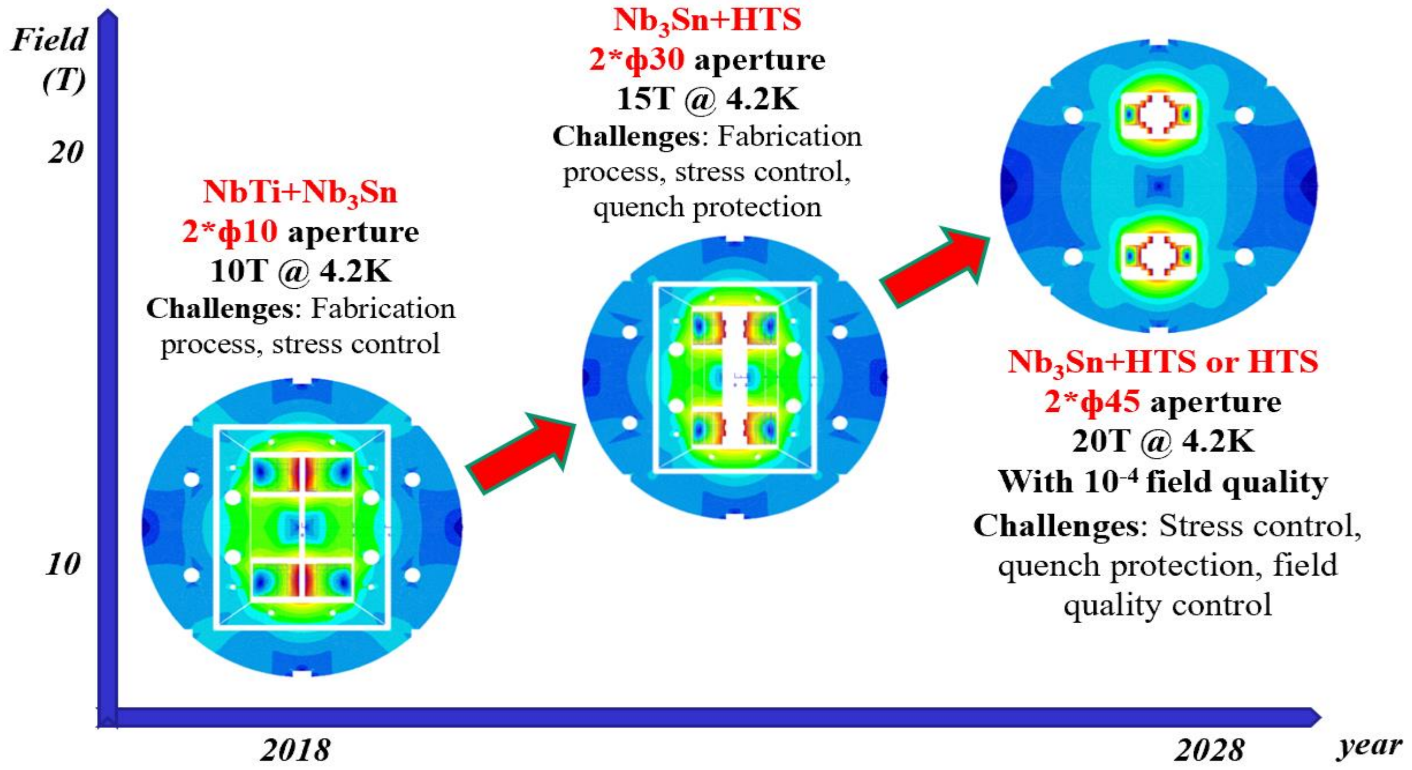


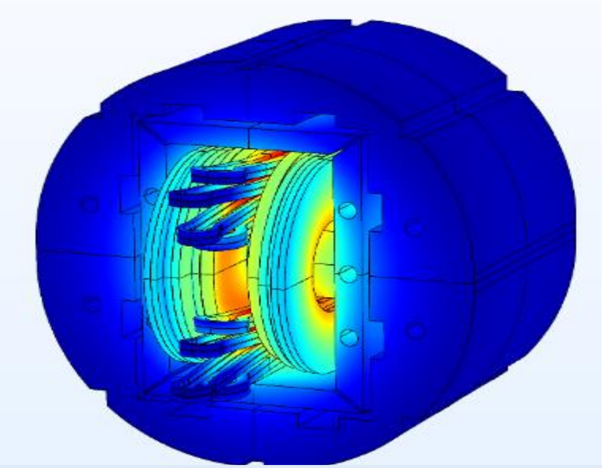
Test results of the 2nd klystron prototype

SPPC R&D: HTS SC Magnet

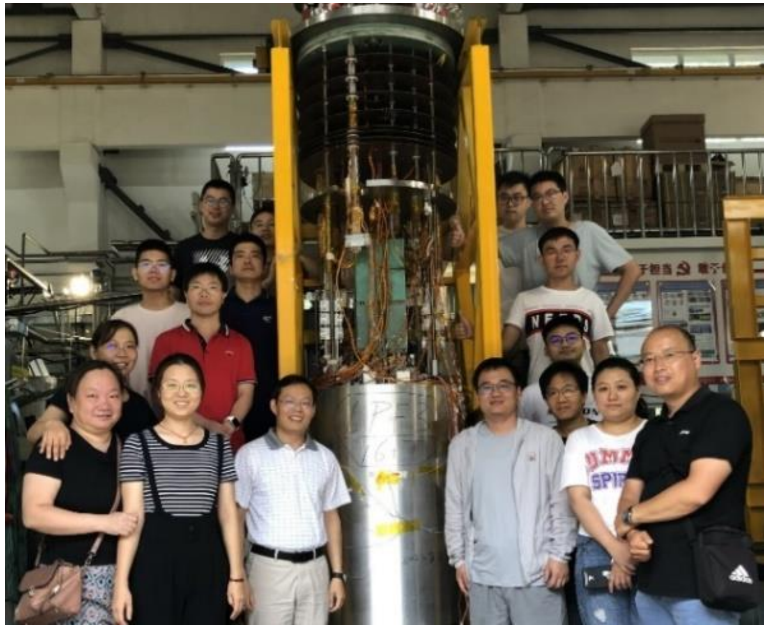
- **2023: SC dipole magnet, field reached 14T @ 4.2K**
- **2024: aiming for 16T @ 4.2K (the world record)**

10.2T (2018) → **12.5T (2021)** → **14T (2023)** → **16T (2024)**





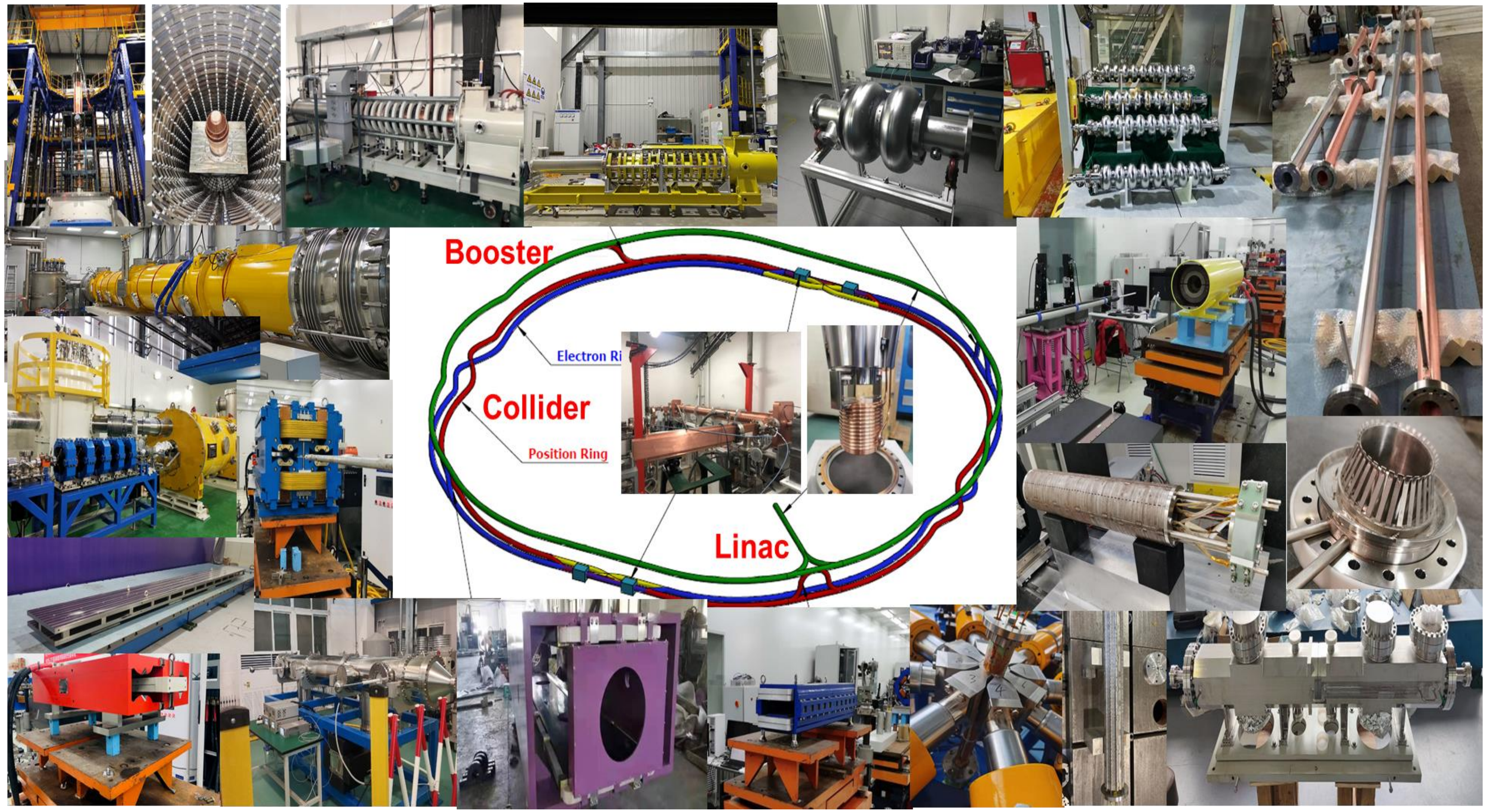
16T dipole (LTS+HTS)



Completion of SC magnet (2023.8)

CEPC R&D: Accelerator Key Technologies

- Key technologies R&D span over all components listed in CDR.
- About 10% remaining (eg. RF power source, control, alignment, SC magnets, machine integration) to be completed by 2026.



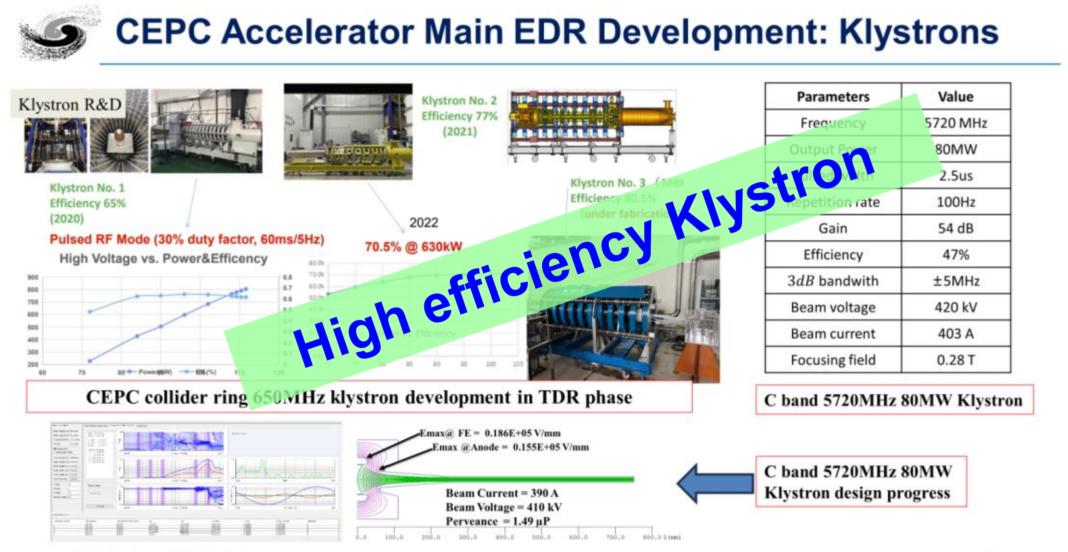
✓ Specification Met

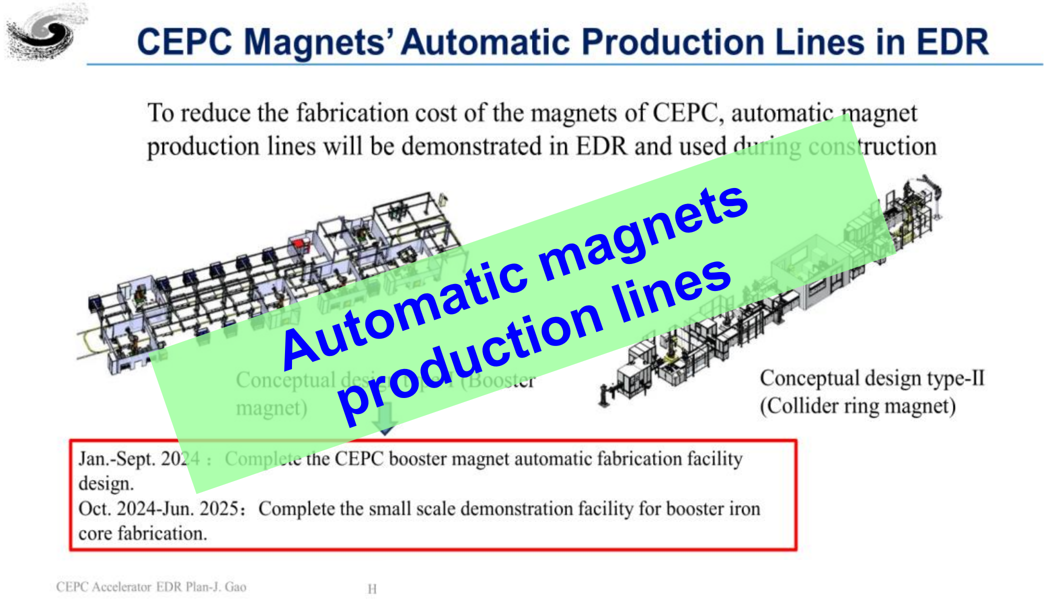
✓ Prototype Manufactured

Accelerator	Fraction
✓ Magnets	27.3%
✓ Vacuum	18.3%
✓ RF power source	9.1%
✓ Mechanics	7.6%
✓ Magnet power supplies	7.0%
✓ SC RF	7.1%
✓ Cryogenics	6.5%
✓ Linac and sources	5.5%
✓ Instrumentation	5.3%
✓ Control	2.4%
✓ Survey and alignment	2.4%
✓ Radiation protection	1.0%
✓ SC magnets	0.4%
✓ Damping ring	0.2%

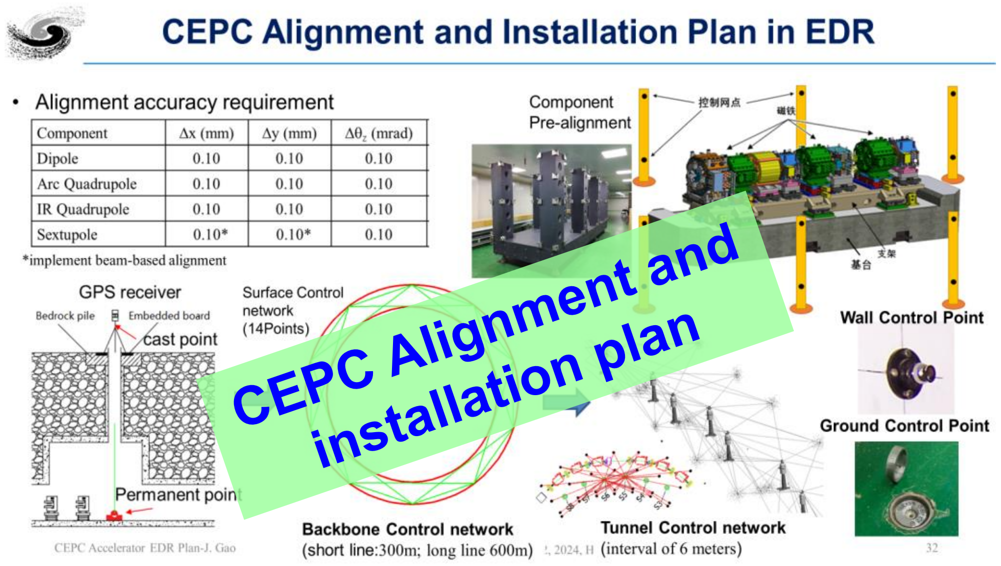
CEPC Accelerator EDR

CEPC Accelerator EDR tasks start with 35 WGs aiming for key issues.

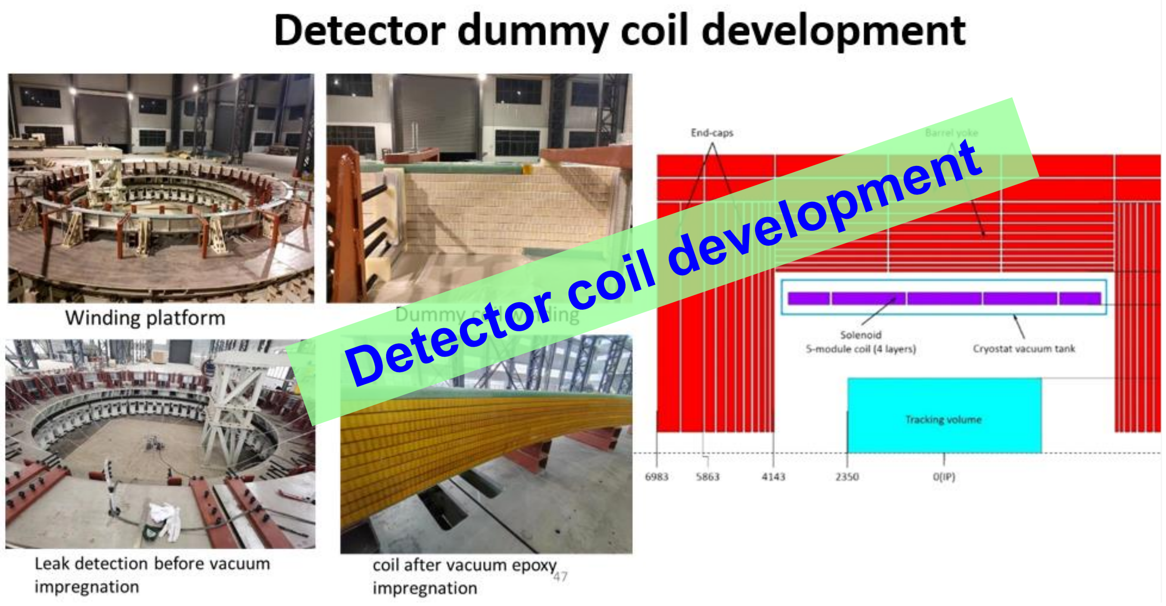


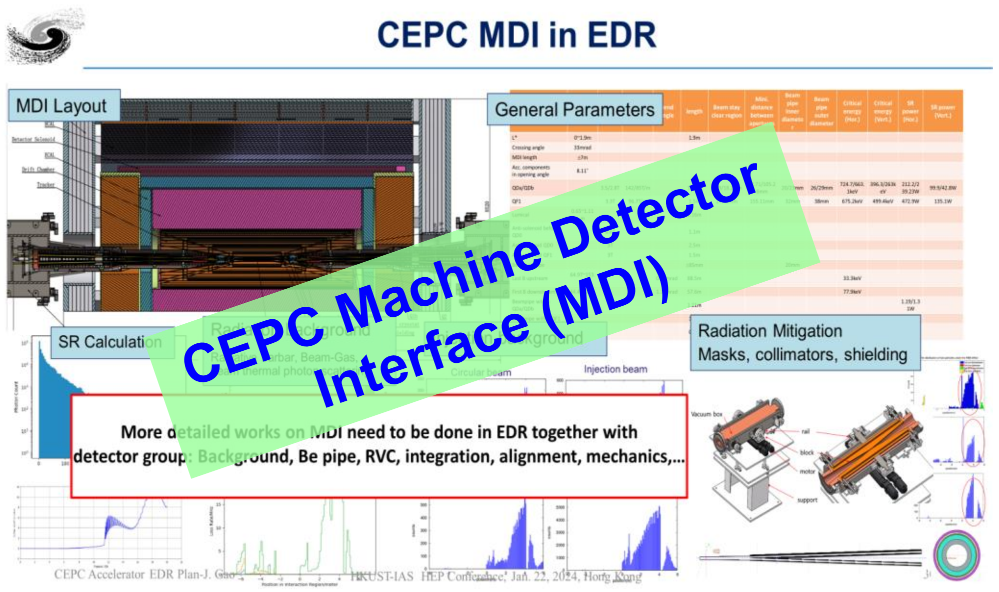


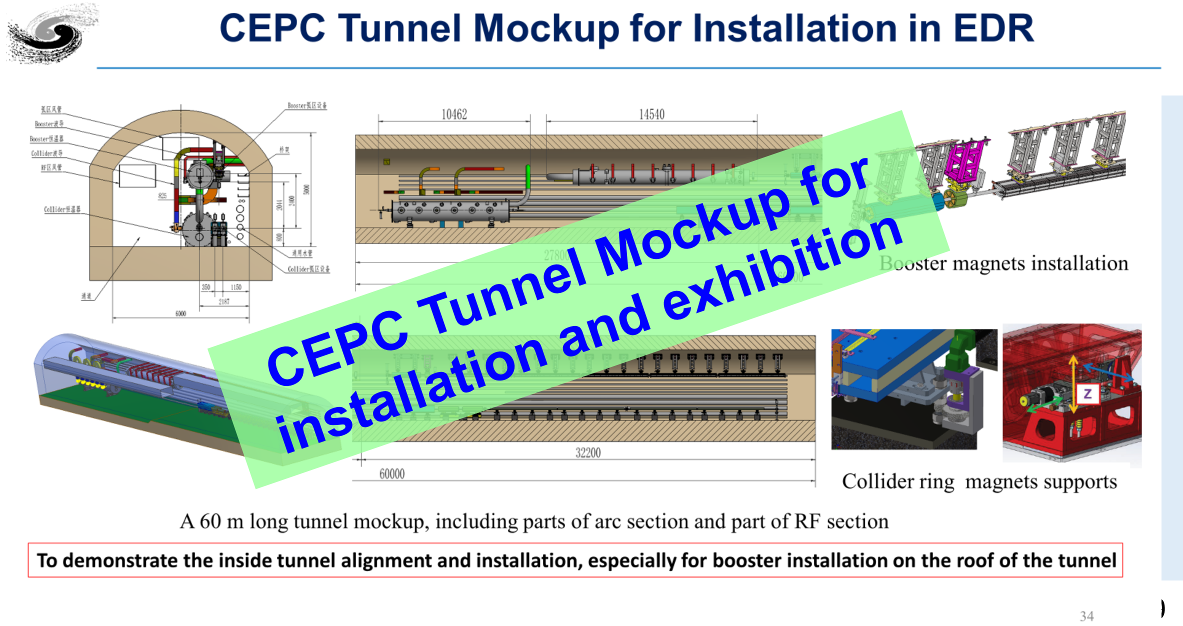
CEPC Accelerator EDR



Component	Δx (mm)	Δy (mm)	$\Delta\theta_z$ (mrad)
Dipole	0.10	0.10	0.10
Arc Quadrupole	0.10	0.10	0.10
IR Quadrupole	0.10	0.10	0.10
Sextupole	0.10*	0.10*	0.10

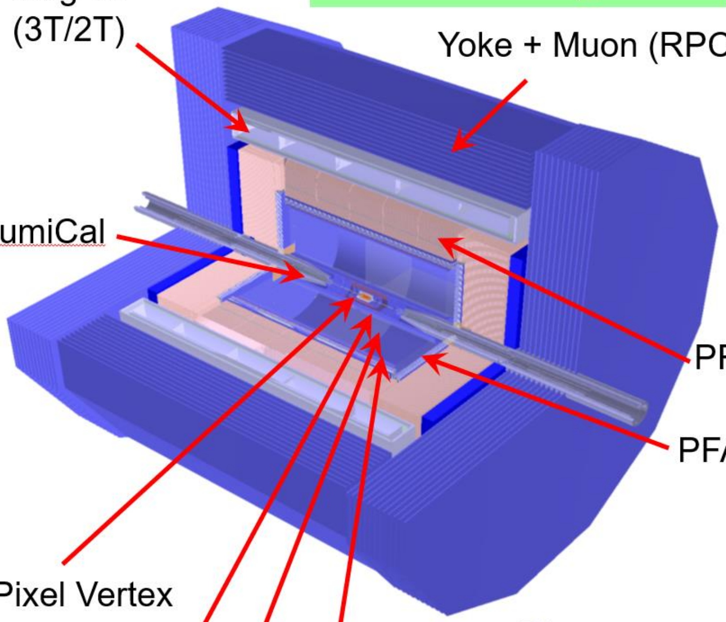




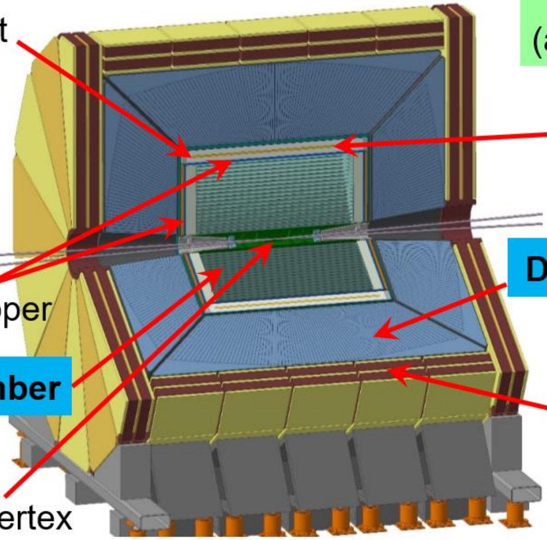


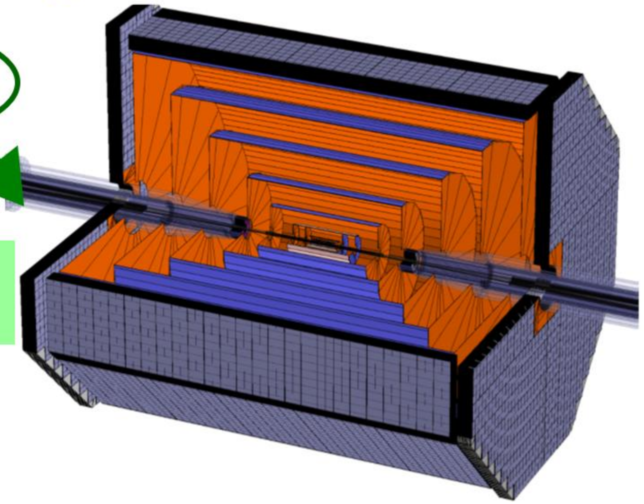
CEPC Detector Concepts → New Design

(Baseline Design)
Particle Flow Approach



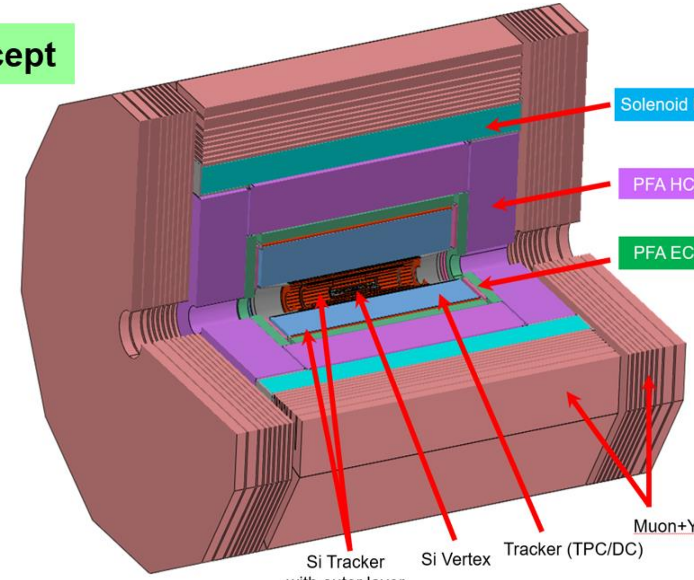
IDEA concept
(also proposed for FCC-ee)





FST concept
(Full Silicon Tracker)

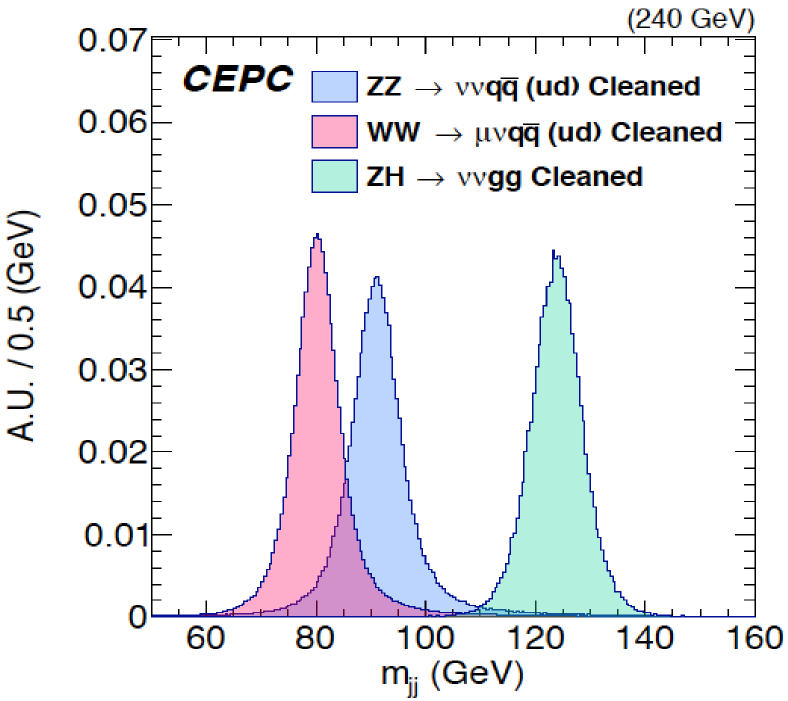
The 4th Concept

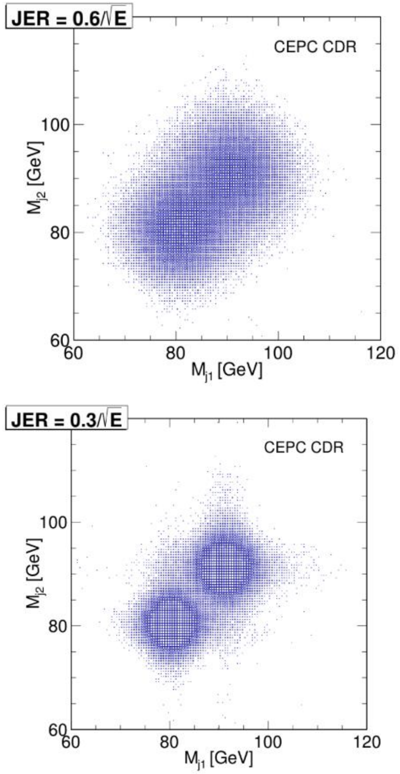


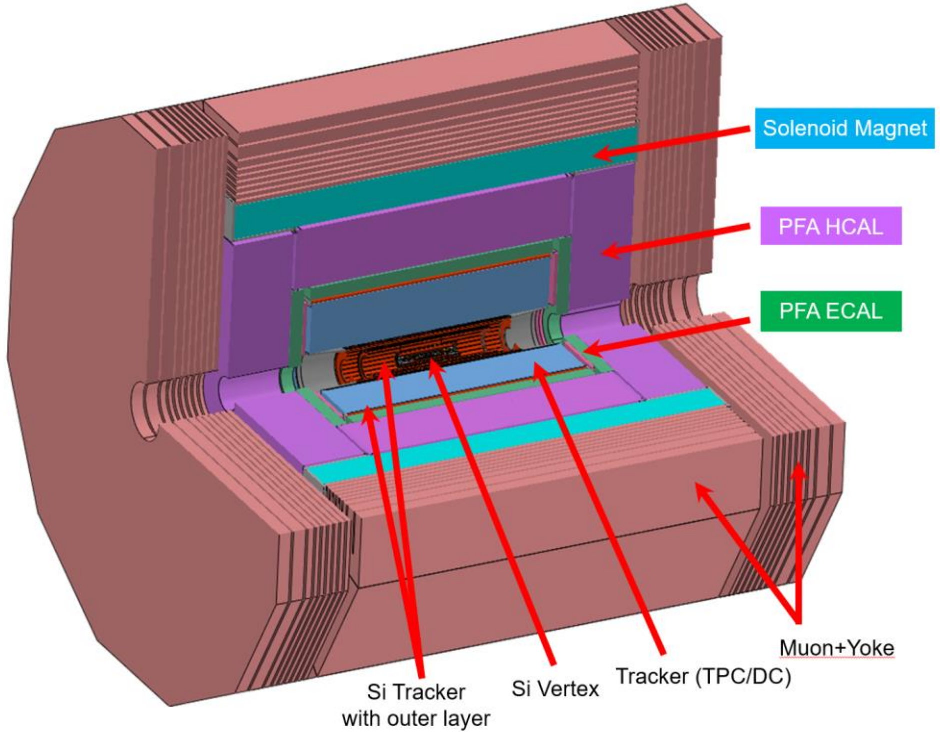
CEPC New Detector Design

Goal: with PFA calorimeters to improve boson mass resolution (BMR) from 4% ➔ 3%。

Calorimeter	World-class	New design
PFA ECAL	～ 15-20% / √E	～ 3% / √E
PFA HCAL	～ 50-60% / √E	～ 40% / √E



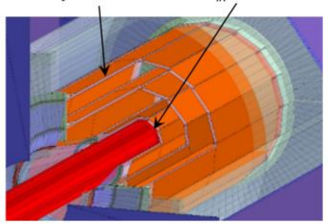




- **Silicon tracker with TPC / DC:**
  to improve track reconstruction & PID
- **PFA ECAL with crystal:**
  to improve π^0, γ energy resolution
- **PFA HCAL with scintillating glass:**
  to improve hadron energy resolution

CEPC Detector R&D: Silicon, TPC, DC Prototypes

2 layers / ladder R_{in}~16 mm



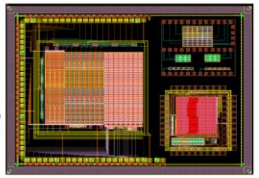
Goal: σ(IP) ~ 5 μm for high P track

CDR design specifications

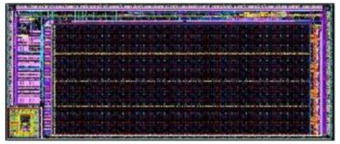
- Single point resolution ~ 3μm
- Low material (0.15% X_0 / layer)
- Low power (< 50 mW/cm²)
- Radiation hard (1 Mrad/year)

Silicon pixel sensor develops in 5 series: JadePix, TaichuPix, CPV, Arcadia, COFFEE

Develop **COFFEE** for a CEPC tracker using SMIC 55nm HV-CMOS process

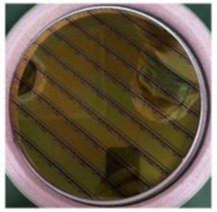


JadePix-3 Pixel size ~16×23 μm²

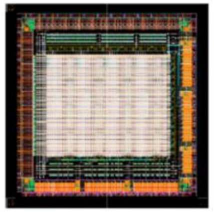


Tower-Jazz 180nm CiS process
Resolution 5 microns, 53mW/cm²

TaichuPix-3, FS 2.5x1.5 cm²
25×25 μm² pixel size

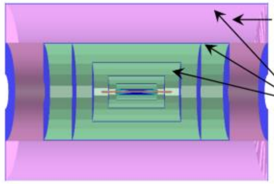


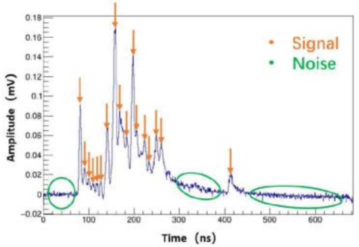
CPV4 (SOI-3D), 64×64 array
~21×17 μm² pixel size

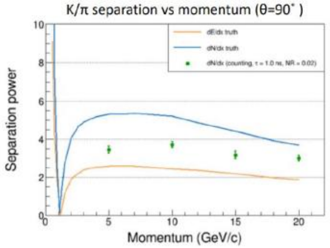


Arcadia by Italian groups for IDEA vertex detector
LFoundry 110 nm CMOS

- **Goal: 3σ π/K separation up to ~20 GeV/c.**
- Cluster counting method, or **dN/dx**, measures the number of primary ionization
- **Can be optimized specifically for PID**: larger cell size, no stereo layers, different gas mixture.
- Garfield++ for simulation, realistic electronics, peak finding algorithm development.







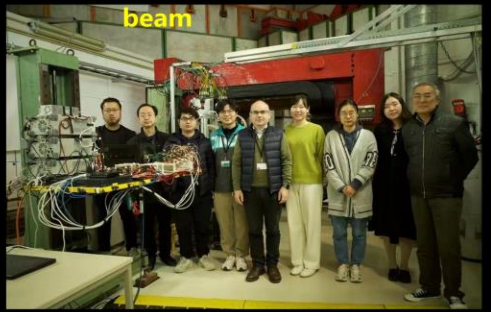
IHEP and Italian INFN groups have close collaboration and regular meetings.
IHEP joined the TB (led by INFN group) in 2021 and 2022

Test beam @ DESY

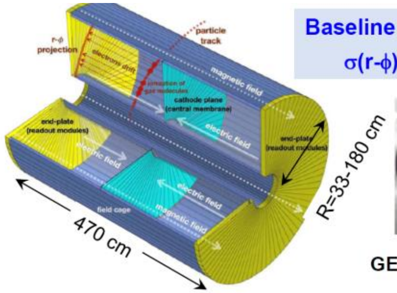
- 2nd testbeam: April 11-23 2023 DESY test beam in Germany (4-6 GeV electron)
  - Vertex detector prototype testbeam
- 1st testbeam: Dec 12-22 2022 DESY test beam in Germany (4-6 GeV electron)
  - TaichuPix Beam Telescope testbeam

2022 DESY test beam

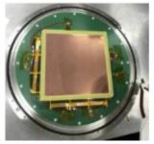
2023 DESY test beam



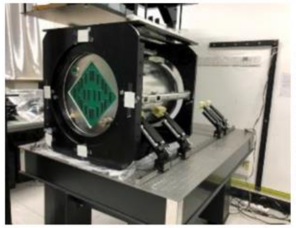
Excellent collaboration with DESY testbeam team



Baseline main tracker
σ(r-ϕ) ~100 μm



GEM-MM cathode

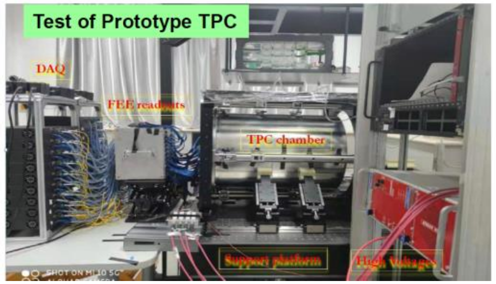


TPC Prototype + UV laser beams

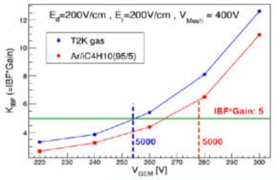
MOST 1 (IHEP+THU)

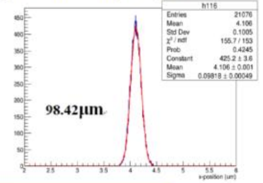
Low power FEE ASIC

Test of Prototype TPC



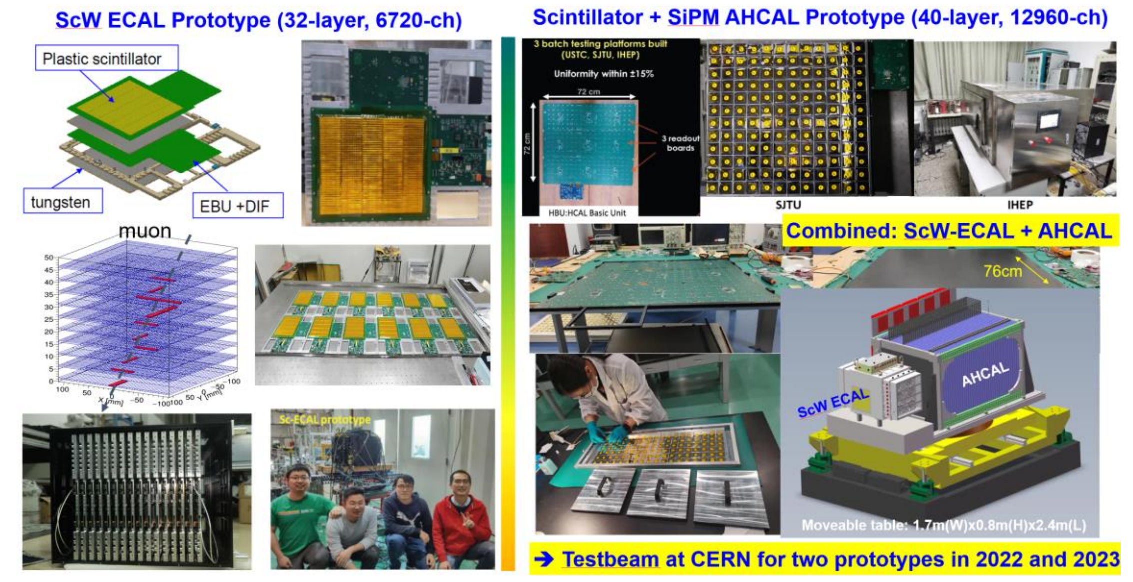
Challenge: Ion backflow (IBF) affects the resolution. It can be corrected by a laser calibration at low luminosity, but difficult at high luminosity Z-pole.



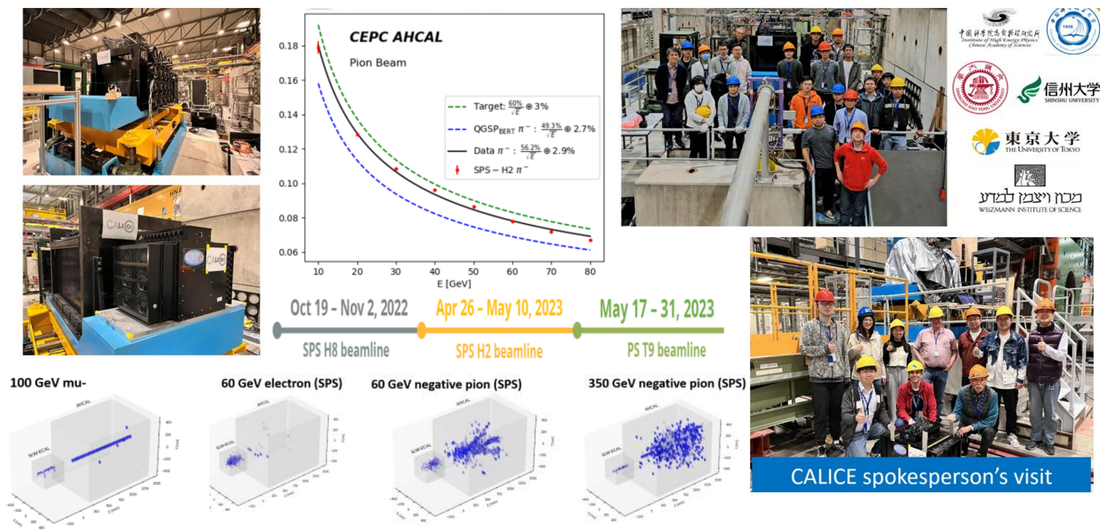


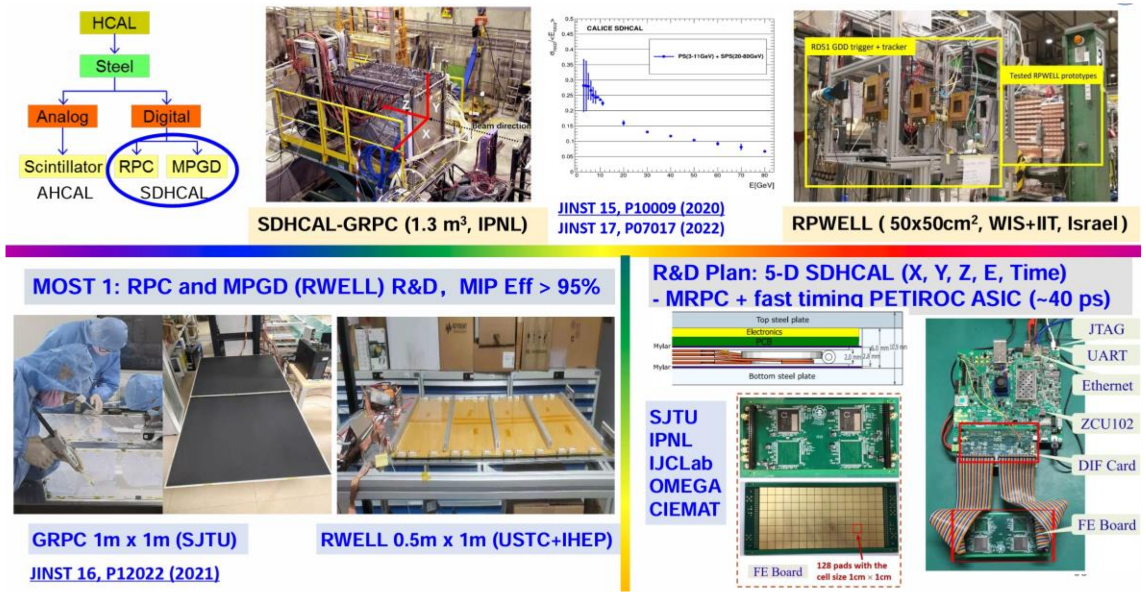
σ < 100 μm for drift length of 27cm

CEPC Detector R&D: Calorimeter Prototypes

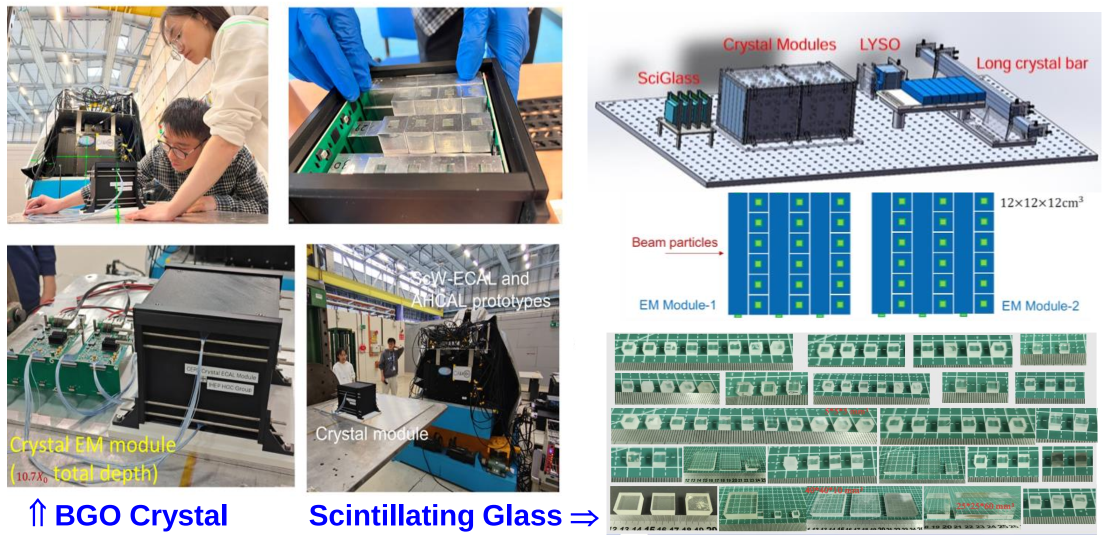


CEPC Calorimeter Prototypes: beam test at CERN in 2022 & 2023





Crystal Modules: beam test at CERN and DESY in 2023 & 2024



CEPC Reference Detector TDR

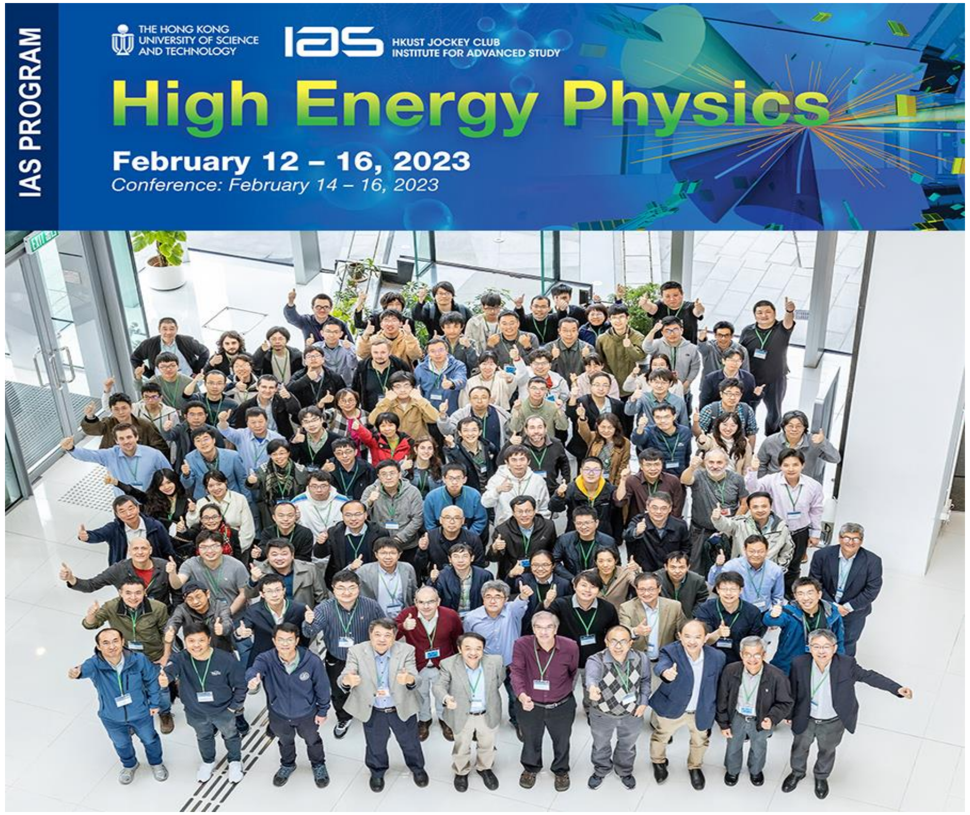
Det	Technology	Det	Technology
Pixel Vertex	JadePix	Calorimeter	Crystal ECAL
	TaichuPix		Stereo Crystal ECAL
	CPV(SOI)		Scint+W ECAL
	Stitching		Si+W ECAL
	Arcadia		Scint+Fe AHCAL
Tracker & PID	CEPCPix		ScintGlass AHCAL
	Silicon Strip		RPC SDHCAL
	TPC		MPGD SDHCAL
	Drift chamber		DR Calorimeter
	PID drift chamber	Muon	Scintillation Bar
	LGAD ToF		RPC
Lumi	SiTrk+Crystal ECAL		μ-Rwell
	SiTrk+SiW ECAL		HTS / LTS Magnet
	CEPC SW		MDI & Integration
	TDAQ		

- **Large number of detector technology options and R&D projects on-going, they are not at similar level of maturity.**
- **Need to converge technology options towards a CEPC reference detector TDR**
  - Start preparation in Jan. 2024
  - A draft version of TDR in Dec. 2024
  - **Official release of TDR in Jun. 2025**
- **Intl. detector collaborative efforts**
  - DRD collaboration (DRD1-8), more than 130 colleagues from 11 Chinese institutes joined so far.
  - HL-LHC detector R&D efforts help to prepare teams for CEPC detectors.

CEPC International Collaboration

CEPC attracts significant International participation

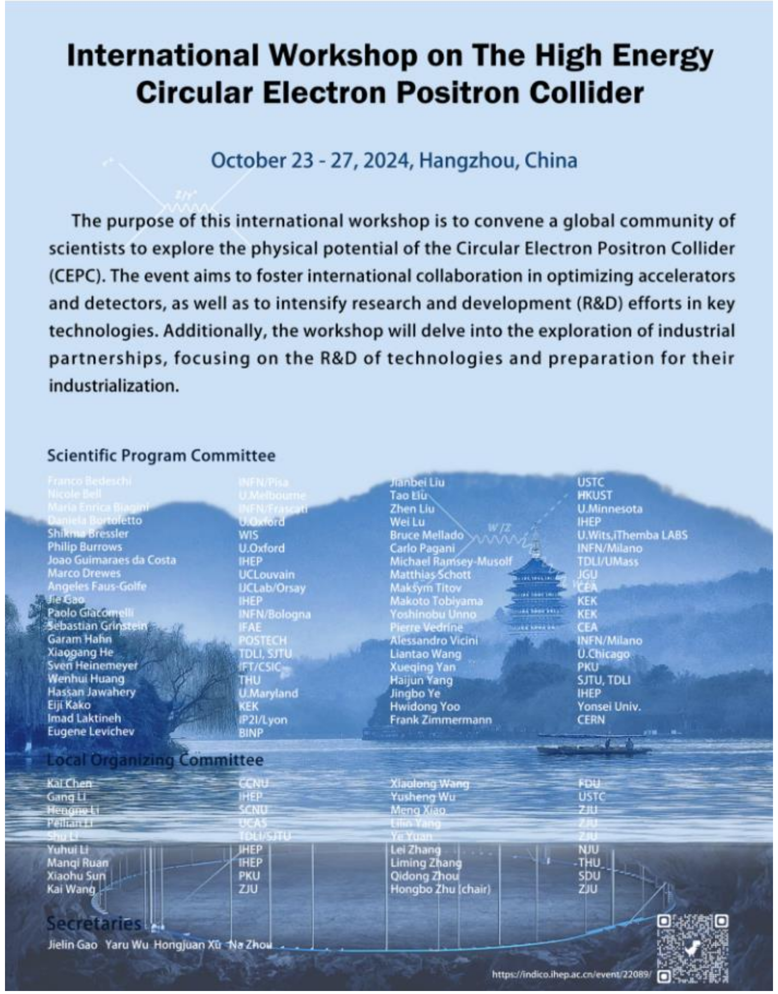
- Both CDR and TDR have significant intl. contributions
- 20+ MoUs signed with Intl. institutions and universities
- Intl. collaborative efforts: DRD & HL-LHC detector R&D
- CEPC International Workshop since 2014
- Annual working month at HKUST-IAS since 2015
- EU-US versions of CEPC Workshop since 2018



Next CEPC Workshop

CEPC International Workshop at Hangzhou, Zhejiang U., Oct. 23-27, 2024

China announced 144-hour visa-free transit policy for 54 selected countries



Industrial Partners and Suppliers Worldwide

	System
1	Magnet
2	Power supplier
3	Vacuum
4	Mechanics
5	RF Power
6	SRF / RF
7	Cryogenics
8	Instrumentation
9	Control
10	Survey and alignment
11	Radiation protection
12	e^-e^+Sources

CEPC Industrial Promotion Consortium (CIPC, established in Nov. 2017)

LEIKE 雷科电子, KAITENG SIFANG, 汉光科技, 北广科技 BBEF, 锐力电工 TOLY ELECTRIC, 高能锐新 HE-RACING TECHNOLOGY, 苏州八匹马超导科技有限公司, PUSU, VACREE, 慧宇 HUI YU, 上海超导, 地矿建设 DIKUANG CONSTRUCTION, 昆山国力电子科技股份有限公司 Kunshan Guoli Electronic Technology Co., Ltd., Western Superconducting Technologies Co.,Ltd., 中科富海 FULLCRYO, 上海辰光医疗科技股份有限公司 Shanghai Chenguang Medical Technologies Co. Ltd, 中船重工鹏力（南京）超低温技术有限公司, 爱科赛博 ACTIONPOWER, 江苏克劳特低温 JiangSu Cryote Co., Ltd, JJ vac 三井真空, 普达迪泰 PRODETEC, 北京航天万源科技有限公司 Beijing Granite Technology Co., Ltd, 中铁装备 CREG, 正帆科技 GENTECH, VACUUM PRODUCTS, SEALTECH, SKY, HUALUN, 东方钽业 OTIC 中国有色集团成员企业, 瑞隆, RAB, HDKY浩德科仪, RuiYuan, 中国铁建, NVT, 冰轮环境 MOON-TECH, JST, 金鑫科技, 东方晨景 East Changing, EDWARDS, CBVAC, 黄河勘测规划设计研究院有限公司 Yellow River Engineering Consulting Co., Ltd., 华东勘测设计研究院 HUADONG ENGINEERING CORPORATION, 中国电建集团昆明勘测设计研究院有限公司, 海南展创光电技术有限公司 HZC PHOTONICS, 中国电建 POWERCHINA

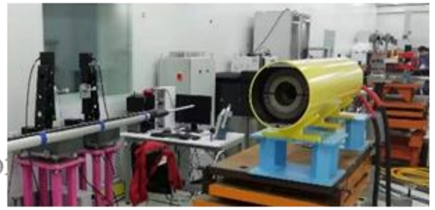
Potential international collaborating suppliers and partners worldwide

DANFYSIK, SCANDITRONIX, TOKINARC TOKIN CORPORATION, HEINZINGER, DAWONSYS, CAEN Technologies Inc., nichicon, Kudos Electrical Contracting, PFEIFFER VACUUM, Leybold, VAT, EDWARDS, mks, Sanei-Kikai Co.,Ltd, VIC INTERNATIONAL, Fujikin, MPC MIRAPRO, CPI Communications & Power Industries, Canon, THALES Building a future we can all trust, Air Liquide, Linde, Lake Shore CRYOTRONICS, Osprey Distributed Control Systems, SGL research, bergoz, INSTRUMENTATION TECHNOLOGIES, COSYLAB, dimtel, ThermoFisher SCIENTIFIC, ELSE NUCLEAR, HEXAGON

The 8th CEPC IAC Meeting 7

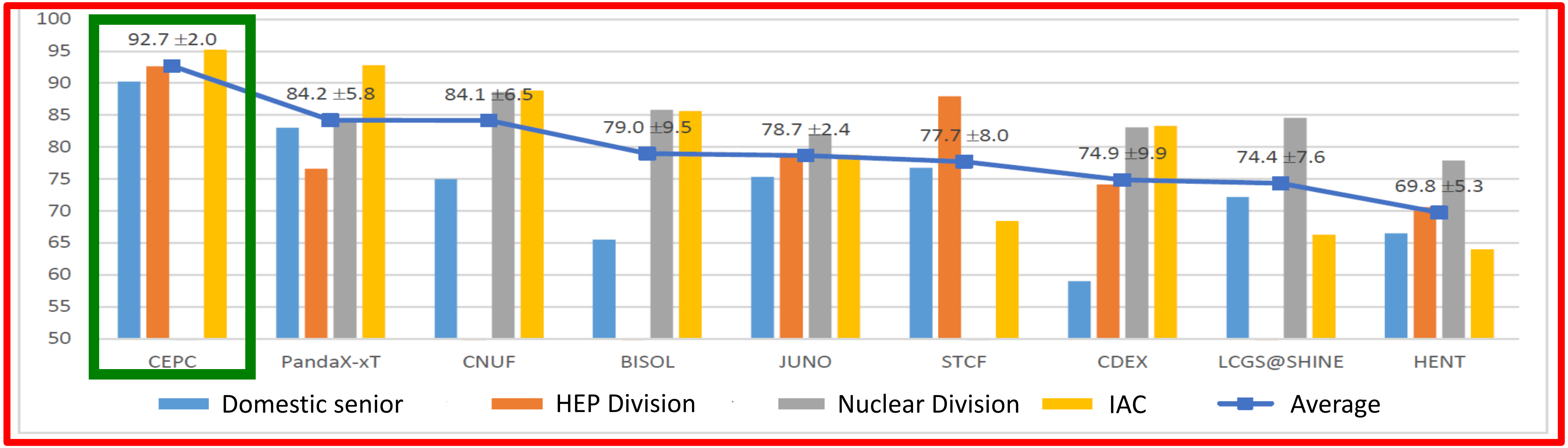





CEPC Planning and Development

- CAS is planning for the 15th 5-year plan for large science projects, and a steering committee has been established, chaired by the president of CAS.
- High energy physics and nuclear physics is one of eight groups (fields).
- CEPC is ranked No. 1， by every committee (2 domestic and 1 international).
- A final report was submitted to CAS for consideration, this process is within CAS, and the following national selection process will be decisive.



CEPC Planning and Schedule

2012.9	2015.3	2018.11	2023.12	2025.6	2027	15th five year plan (2026-2030)
proposed	Pre-CDR	CDR	Acc. TDR	Det. TDR	EDR	Start of construction

CEPC EDR Phase: 2024-2027

- **CEPC Accelerator EDR** starts with 35 WGs in 2024, to be completed in **2027**
- **CEPC Reference Detector TDR** will be released by June, **2025**
- **CEPC proposal** will be submitted to the Chinese government for approval in **2025**
- **Upon approval**, establish at least two international collaborations on experiments
- **CEPC construction starts** during the 15^{th} five-year plan (2026-2030, e.g. **2027**)
- **CEPC construction complete** around **2035**, at the end of the 16^{th} five-year plan

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NEWS | 17 June 2024 | Correction 18 June 2024

China could start building world's biggest particle collider in 2027

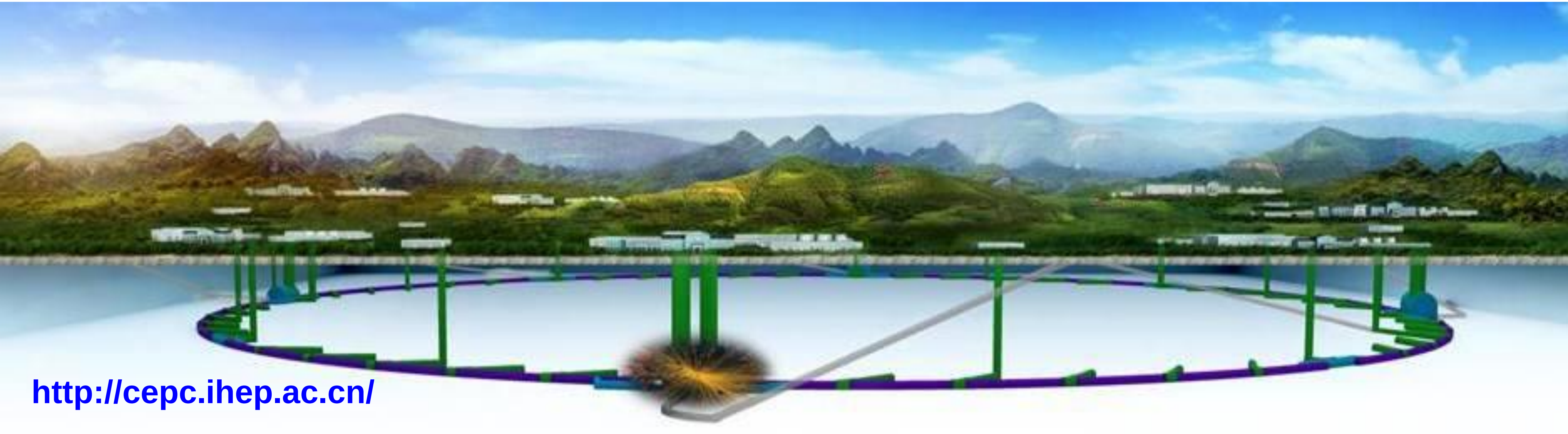
The US$5 billion facility would be cheaper, bigger and faster to build than a similar one proposed by European scientists.

Summary

- CEPC addresses many most pressing and critical science problems in particle physics.
- Accelerator design and technology R&D are reaching maturity, TDR completed, enters EDR phase, ready for construction in 3-5 years.
- Reference detector TDR under preparation, to be completed by the mid-2025 for the proposal of China's 15th 5-year plan.
- Contributions from international colleagues for both accelerator EDR and reference detector TDR are warmly welcome.
- CEPC schedule will follow the 15th 5-year plan, call for international collaborations and proposals once CEPC is approved.
- CEPC will offer the worldwide HEP community an early Higgs factory.

Acknowledgement

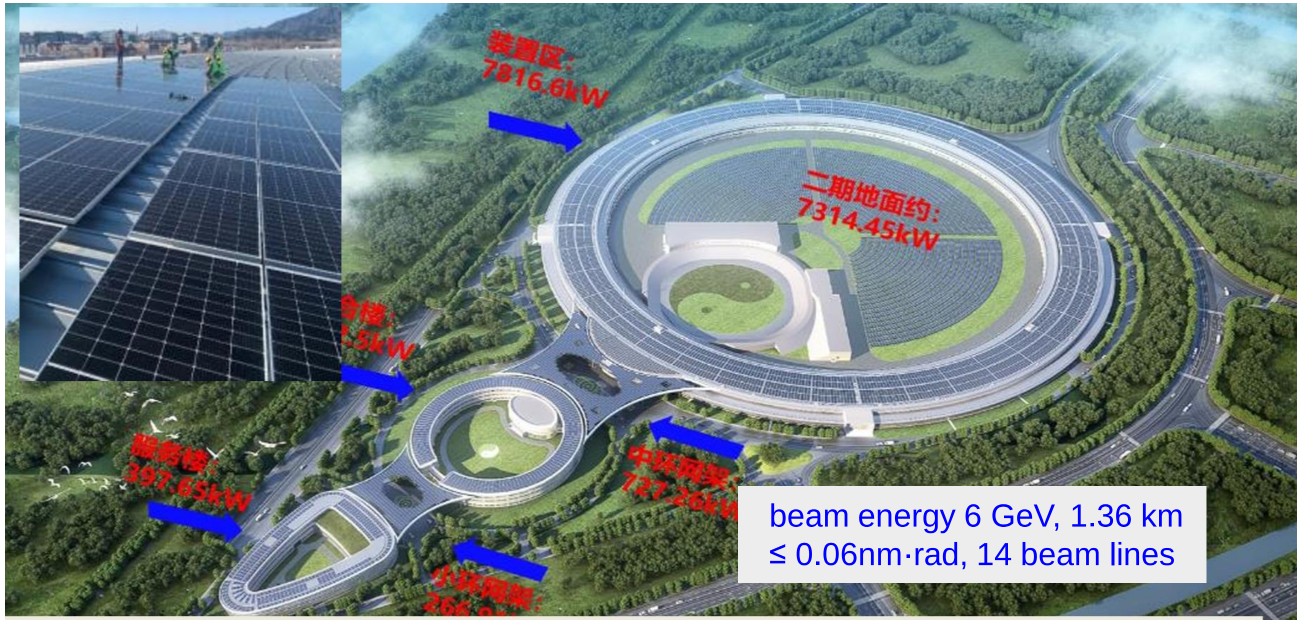
Thanks to CEPC team for enormous efforts and achievements
Special thanks to CEPC IAC, IARC and TDR review committee



http://cepc.ihep.ac.cn/

High Energy Photon Source (HEPS)

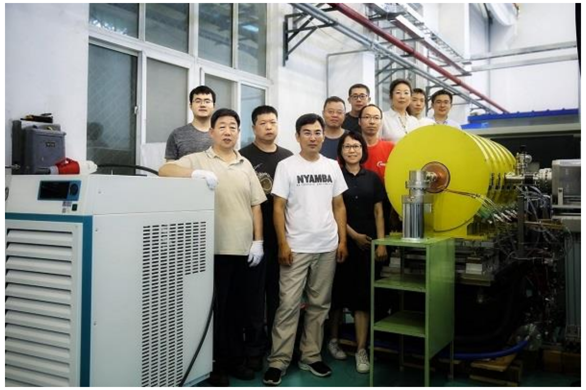
To be completed in 2025, great training and preparation for CEPC ➔ towards a green accelerator



Solar panel on the roof of HEPS

Experience at HEPS

- Solar panel:10 MW ➔ 10% saving
- Permanent magnet: 5.6 GWh saving/year
- Hot water (13 MW @ 42 ^{0}C) for heating



CEPC vs FCC-ee

Table 1: Luminosity per IP (10^{34} cm^{-2}s^{-1})

	Operation mode			
	H	Z	W	$t\bar{t}$
CEPC (TDR, 30 MW)	5	115	16	0.5
CEPC (TDR, 50 MW)	8.3	192	26.7	0.8
FCC-ee (FS MTR, 50 MW)	≥ 5.0	140	20	1.25

Table 2: Integrated Luminosity per Year per IP (ab^{-1}/yr/IP)

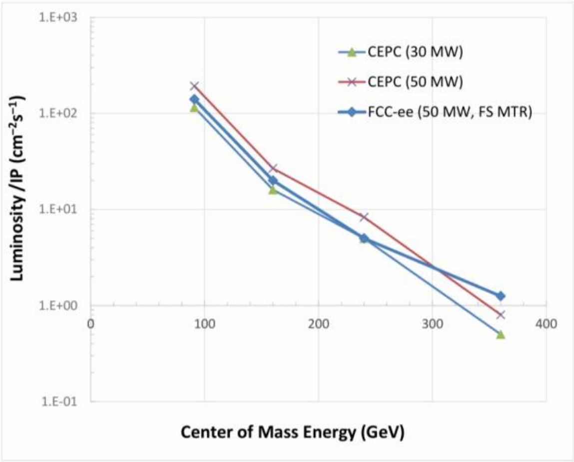
	Operation mode			
	H	Z	W	$t\bar{t}$
CEPC (TDR, 30 MW)	0.65	15	2.1	0.065
CEPC (TDR, 50 MW)	1.1	25	3.5	0.1
FCC-ee (FS MTR, 50 MW)	0.6	17	2.4	0.15

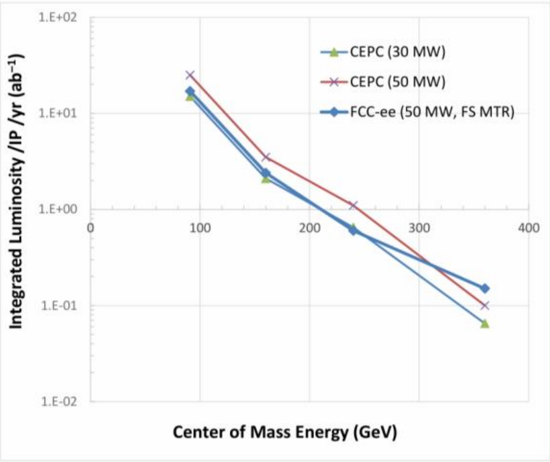
Table 3: Total Integrated Luminosity per Year (ab^{-1}/yr)

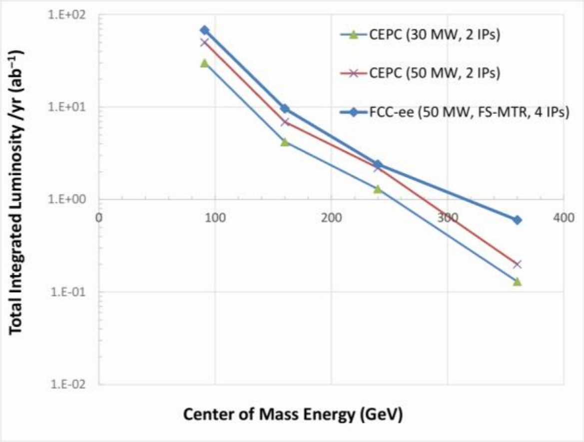
	Operation mode			
	H	Z	W	$t\bar{t}$
CEPC (TDR, 30 MW, 2 IPs)	1.3	30	4.2	0.13
CEPC (TDR, 50 MW, 2 IPs)	2.2	50	6.9	0.2
FCC-ee (FS MTR, 50 MW, 4 IPs)	2.4	68	9.6	0.6

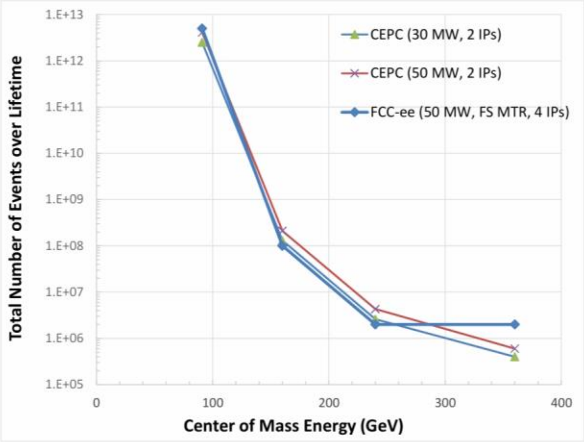
Table 4: Total Number of Events over the Machine Lifetime

	Operation mode			
	H	Z	W	$t\bar{t}$
CEPC (TDR, 30 MW)	2.6×10^6	2.5×10^{12}	1.3×10^8	0.4×10^6
CEPC (TDR, 50 MW)	4.3×10^6	4.1×10^{12}	2.1×10^8	0.6×10^6
FCC-ee (FS MTR, 50 MW)	2×10^6	5×10^{12}	$> 1 \times 10^8$	2×10^6



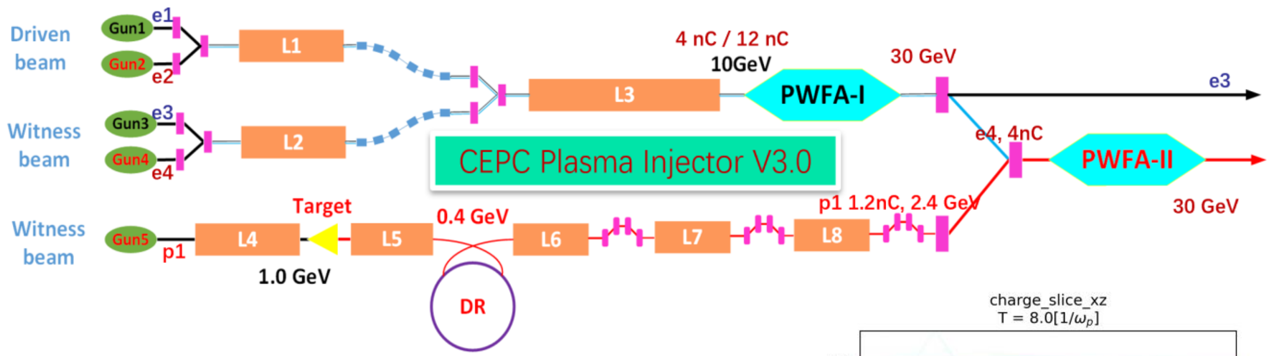






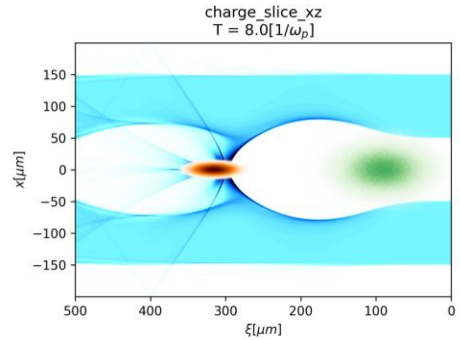
CEPC Accelerator: Plasma Injector

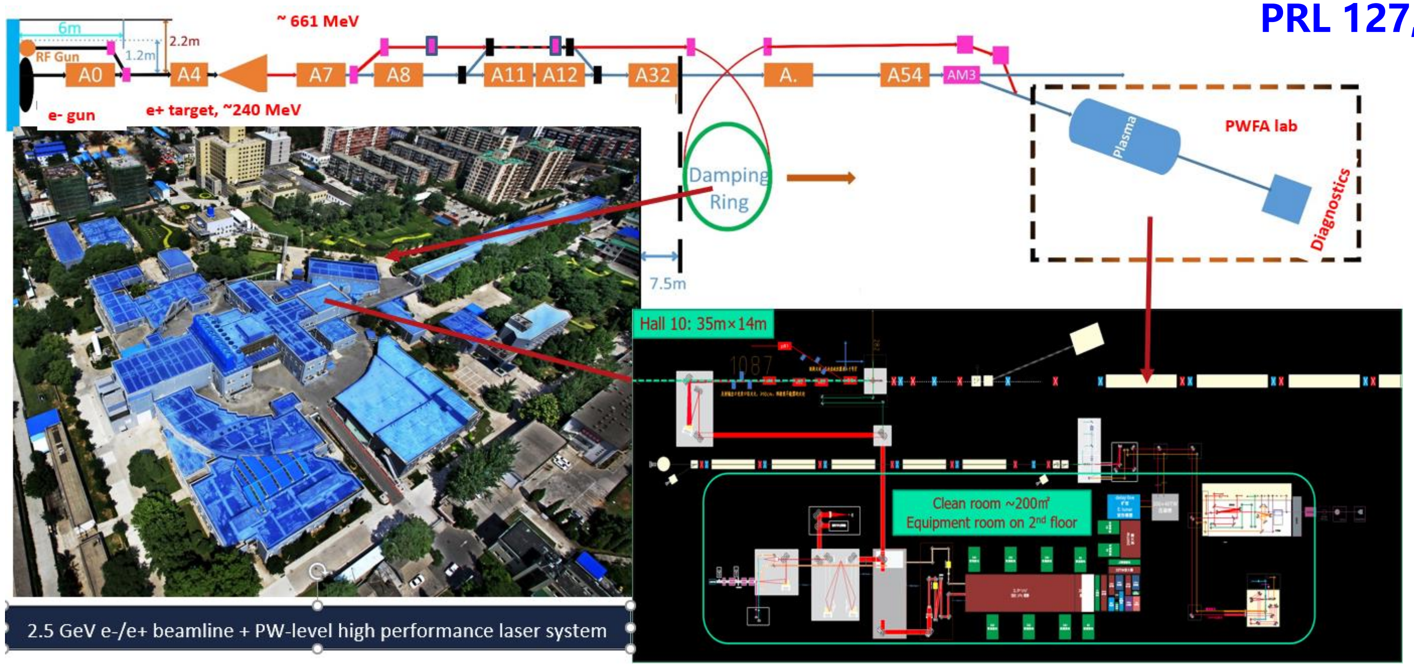
CEPC Plasma Injector Scheme
From 10 GeV → 30 GeV → TR ≥2



Simulation results show that it works on paper with reasonable error tolerances for both electron & positron beams injected to booster

PRL 127, 174801 (2021)





Phase I（Year0-Year2）

1. Re-design and install transport beamline and FF system, optimize the e- / e+ beam quality
2. Clean room and high power laser system (20… installation200TW
3. Beam instrumentation s…
4. RF Gun platform…
5. Comm…

Phase II（…

1. Up… …20/40 TW)
2. Test… …install it on the BEPC…

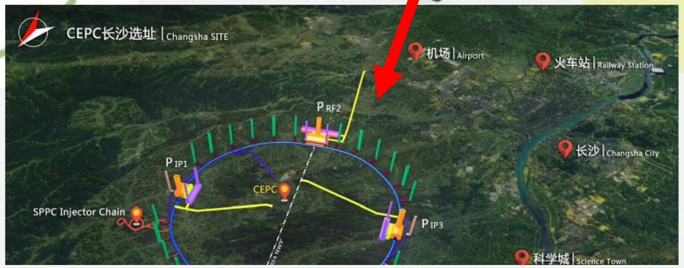
Phase III（Year…

1. Add a positron dumping ring the bunch compression beamline to improve the e+ quality
2. PBA-based FEL studies

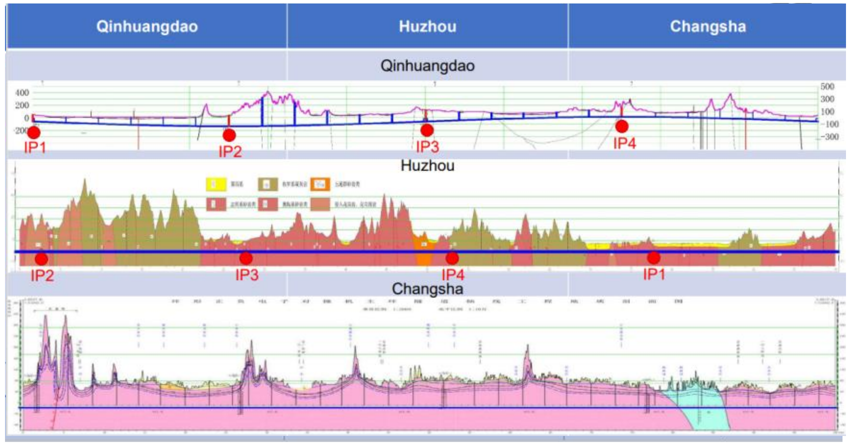
- **Positron and electron acceleration**
- **Cascading acceleration**
- **Future linear collider technologies**
- **High energy beam for detector R&D (possible application)**

PWFA/LWFA TF based on BEPC-II Linac and HPL has founded by CAS, 120M RMB in Sept. 2023

CEPC Site Selection



Huzhou

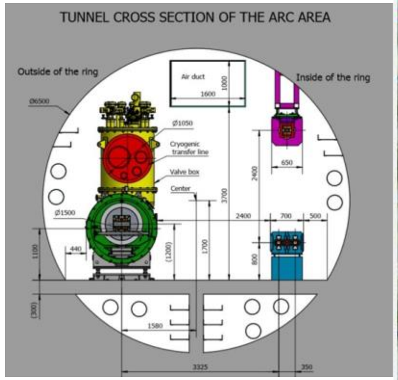


Changsha

中国电建 POWERCHINA 中国电建集团华东勘测设计研究院有限公司 HUADONG ENGINEERING CORPORATION LIMITED

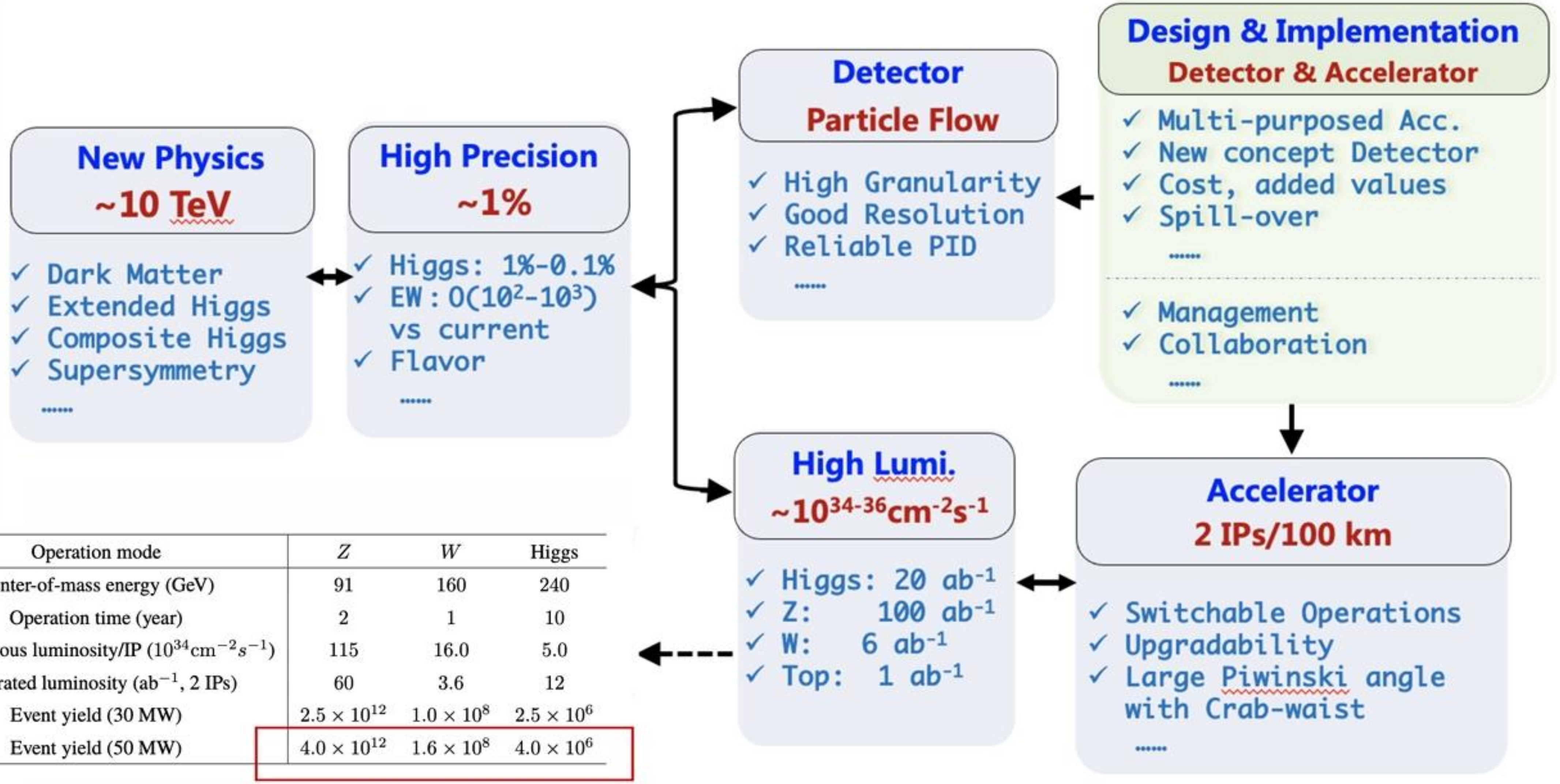
中国电建 POWERCHINA 中南勘测设计研究院有限公司 ZHONGNAN ENGINEERING CORPORATION LIMITED

- 3 sites documented in accelerator TDR
- 75-95% of tunnel in granite, low cost



TBM tunnel

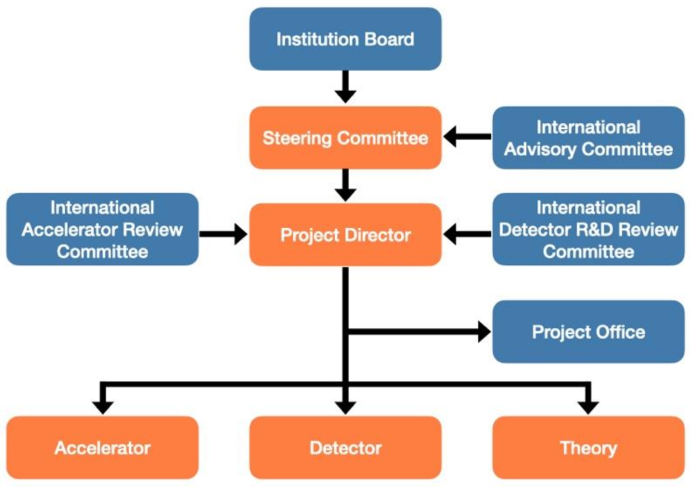
CEPC Key Scientific Issues and Technologies Route



Operation mode	Z	W	Higgs
Center-of-mass energy (GeV)	91	160	240
Operation time (year)	2	1	10
Instantaneous luminosity/IP ($10^{34}\text{cm}^{-2}s^{-1}$)	115	16.0	5.0
Integrated luminosity (ab^{-1}, 2 IPs)	60	3.6	12
Event yield (30 MW)	2.5×10^{12}	1.0×10^{8}	2.5×10^{6}
Event yield (50 MW)	4.0×10^{12}	1.6×10^{8}	4.0×10^{6}

CEPC Team

CEPC Organization



- **Institution Board:** 32 institutes, top universities/institutes in China
- **Management team:** comprehensive management experience at construction projects of BEPCII/CSNS/HEPS, and international projects of BESIII/Daya Bay/JUNO/…
- **Accelerator team:** fully over all disciplines with rich experiences at BEPCII, HEPS…
- **Physics and Detector team:** fully over all disciplines with rich experiences at BESIII, Daya Bay, JUNO, ATLAS, CMS, LHCb …

Table 7.2: Team of Leading and core scientists of the CEPC

Name	Brief introduction	Role in the CEPC team
Yifang Wang	Academician of the CAS, director of IHEP	The leader of CEPC, chair of the SC
Xinchou Lou	Professor of IHEP	Project manager, member of the SC
Yuanning Gao	Academician of the CAS, head of physics school of PKU	Chair of the IB, member of the SC
Jie Gao	Professor of IHEP	Convener of accelerator group, vice chair of the IB, member of the SC
Haijun Yang	Professor of SJTU	Deputy project manager, member of the SC
Jianbei Liu	Professor of USTC	Convener of detector group, member of the SC
Hongjian He	Professor of USTC	Convener of theory group, member of the SC
Shan Jin	Professor of NJU	Member of the SC
Nu Xu	Professor of IMP	Member of the SC
Meng Wang	Professor of SDU	Member of the SC
Qinghong Cao	Professor of PKU	Member of the SC
Wei Lu	Professor of THU	Member of the SC
Joao Guimaraes da Costa	Professor of IHEP	Convener of detector group
Jianchun Wang	Professor of IHEP	Convener of detector group
Yuhui Li	Professor of IHEP	Convener of accelerator group
Chenghui Yu	Professor of IHEP	Convener of accelerator group
Jingyu Tang	Professor of IHEP	Convener of accelerator group
Xiaogang He	Professor of SJTU	Convener of theory group
Jianping Ma	Professor of ITP	Convener of theory group

Management team, leading scientists

Table 7.3: Team of the CEPC accelerator system

Number	Sub-system	Convener	Team (senior staff)
1	Accelerator physics	Chenghui Yu, Yuan Zhang	18
2	Magnets	Wen Kang, Fusan Chen	12
3	Cryogenic system	Rui Ge, Ruixiong Han	11
4	SC RF system	Jiyuan Zhai, Peng Sha	12
5	Beam Instrumentation	Yunfeng Sui, Junhui Yue	7
6	SC magnets	Qingjin Xu	10
7	Power supply	Bin Chen, Fengli Long	9
8	Injection & extraction	Jinhui Chen	7
9	Mechanical system	Jianli Wang, Lan Dong	4
10	Vacuum system	Haiyi Dong, Yongsheng Ma	5
11	Control system	Ge lei, Gang Li	6
12	Linac injector	Jingyi Li, Jingru Zhang	13
13	Radiation protection	Zhongjian Ma	3
Sum			117

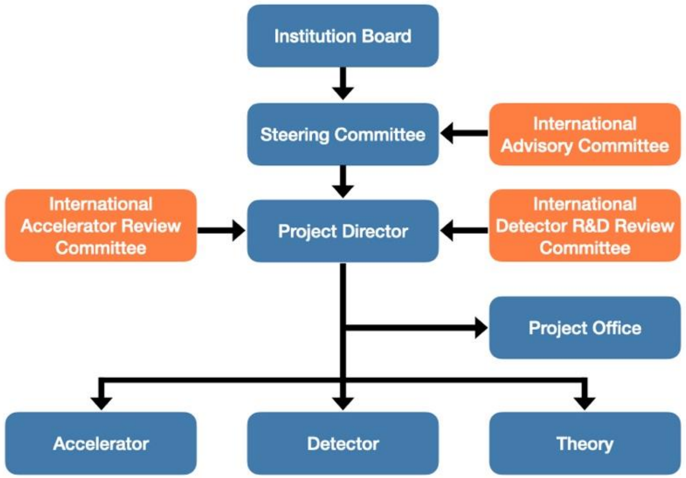
Table 7.4: Team of the CEPC detector system

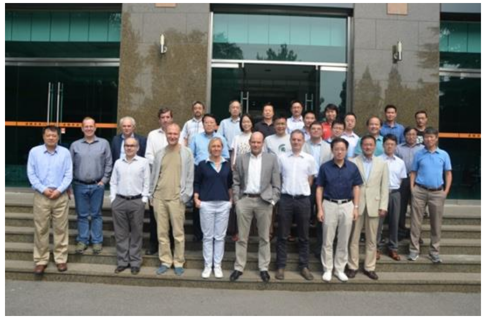
Number	Sub-system	Conveners	Institutions	Team (senior staff)
1	Pixel Vertex Detector	Zhijun Liang, Qun Ouyang, Xiangming Sun , Wei Wei	CCNU, IFAE, IHEP, NJU, NWPU, SDU, Strasbourg, ...	~ 40
2	Silicon Tracker	Harald Fox, Meng Wang, Hongbo Zhu	IHEP, INFN, KIT, Lancaster, Oxford, Queen Mary, RAL, SDU, Tsinghua, Bristol, Edinburgh, Livepool, USTC, Warwick, Sheffield, ZJU, ...	~ 60
3	Gaseous detector	Franco Bedeschi, Zhi Deng, Mingyi Dong, Huirong Qi	CEA Saclay, DESY, LCTPC Collab., IHEP, INFN, NIKHEF, THU ...	~ 30
4	Magnet	Feipeng Ning	IHEP	~ 10
5	Calorimetry	Roberto Ferrari, Jianbei Liu, Haijun Yang, Yong Liu	CALICE Collab., IHEP, INFN, SJTU, USTC..	~ 40
6	Muon	Paolo Giacomelli, Liang Li, Xiaolong Wang	FDU, IHEP, INFN, SJTU ...	~ 20
7	Physics	Manqi Ruan, Yaquan Fang, Liantao Wang, Mingshui Chen	IHEP, FDU, SJTU, ...	~ 80
8	Software	Shengseng Sun, Weidong Li, Xingtao Huang	IHEP, SDU, FDU, ...	~ 20
Sum				~ 300

117 accelerator + ~300 detector staffs currently, + ~ 400 from BEPC/BESIII/JUNO/HEPS/… once CEPC approved

CEPC International Committees

CEPC Organization





International Advisory Committees

Name	Affiliation	Country
Tatsuya Nakada	EPFL	Japan
Steinar Stapnes	CERN	Norway
Rohini Godbole	CHEP, Bangalore	India
Michelangelo Mangano	CERN	Switzerland
Michael Davier	LAL	France
Lucie Linssen	CERN	Holland
Luciano Maiani	U. Rome	San Marino
Joe Lykken	Fermilab	U.S.
Ian Shipsey	Oxford/DESY	U.K.
Hitoshi Murayama	IPMU/UC Berkeley	Japan
Geoffrey Taylor	U. Melbourne	Australia
Eugene Levichev	BINP	Russia
David Gross	UC Santa Barbara	U.S.
Brian Foster	Oxford	U.K
Marcel Demarteau	ORNL	USA
Barry Barish	Caltech	USA
Maria Enrica Biagini	INFN Frascati	Italy
Yuan-Hann Chang	IPAS	Taiwan, China
Akira Yamamoto	KEK	Japan
Hongwei Zhao	Institute of Modern Physics, CAS	China
Andrew Cohen	University of Science and Techbnology	Hong Kong, China
Karl Jakobs	University of Freiburg/CERN	Germany
Beate Heinemann	DESY	Germany

International Accelerator Review Committee

- Phillip Bambade, LAL
- Marica Enrica Biagini (Chair), INFN
- Brian Foster, DESY/University of Hamburg & Oxford University
- In-Soo Ko, POSTTECH
- Eugene Levichev, BINP
- Katsunobu Oide, CERN & KEK
- Anatolii Sidorin, JINR
- Steinar Stapnes, CERN
- Makoto Tobiyama, KEK
- Zhentang Zhao, SINAP
- Norihito Ohuchi, KEK
- Carlo Pagani, INFN-Milano

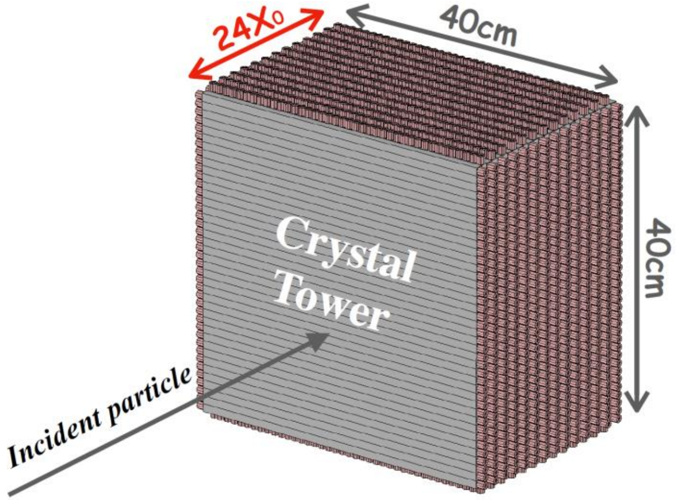
International Detector R&D Review Committee

- Jim Brau, USA, Oregon
- Valter Bonvicini, Italy, Trieste
- Ariella Cattai, CERN, CERN
- Cristinel Diaconu, France, Marseille
- Brian Foster, UK, Oxford
- Liang Han, China, USTC
- Dave Newbold, UK, RAL (chair)
- Andreas Schopper, CERN, CERN
- Abe Seiden, USA, UCSC
- Laurent Serin, France, LAL
- Steinar Stapnes, CERN, CERN
- Roberto Tenchini, Italy, INFN
- Ivan Villa Alvarez, Spain, Santader
- Hitoshi Yamamoto, Japan, Tohoku

- **IAC: global renowned scientists and top laboratory or project leaders who have ample experience in project management, planning, and execution of strategies, operating since 2015**
- **IARC & IDRC: leading experts of this field, provide guide to the project director**

CEPC R&D: Calorimeters with PFA

Crystal ECAL



Energy resolution ~3%/√E ⊕ ~ 1%

Features：

- Good energy resolution
- 3D shower info. with limited readout channel
- Shower separation < 4 cm

Main issues for R&D

- Jet reconstruction and PFA algorithm

Scintillation Glass HCAL

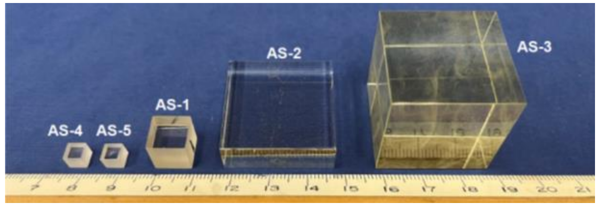
Energy resolution ~40%/√E ⊕ ~ 2%

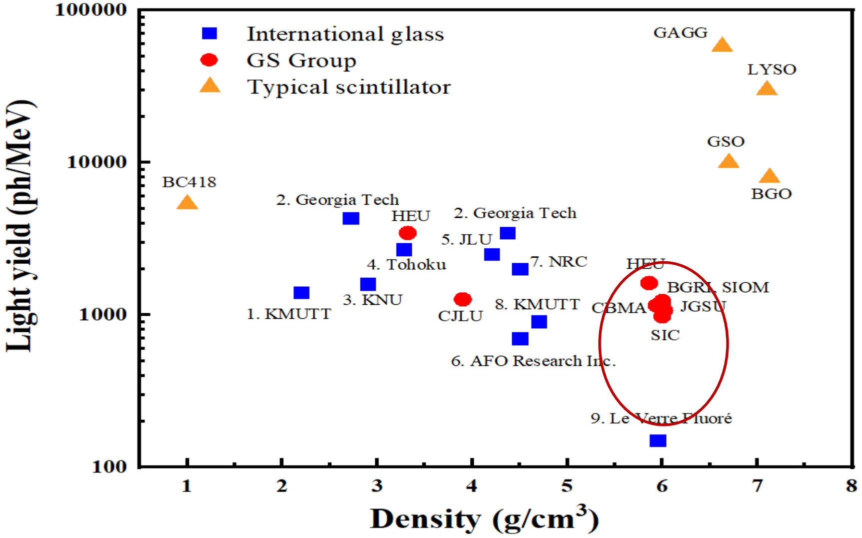
Features：

- Large sampling ratio at low cost

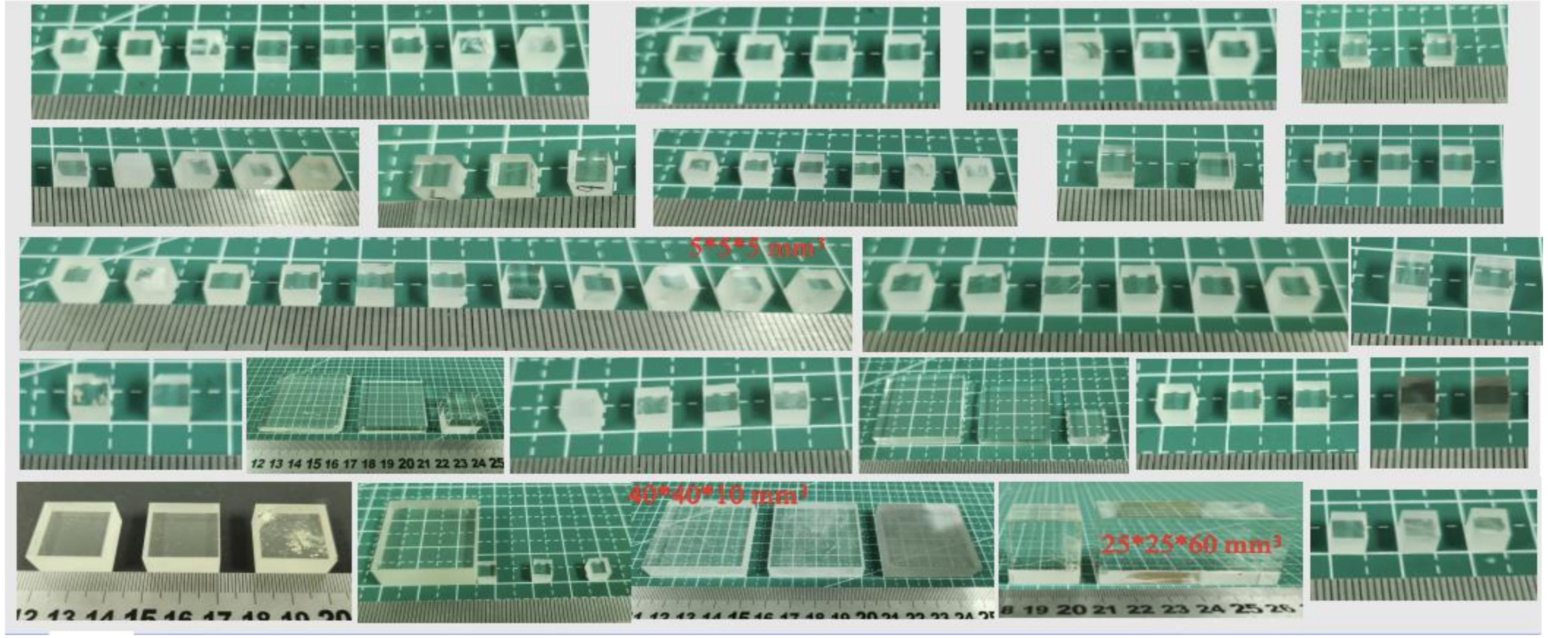
Main issues for R&D

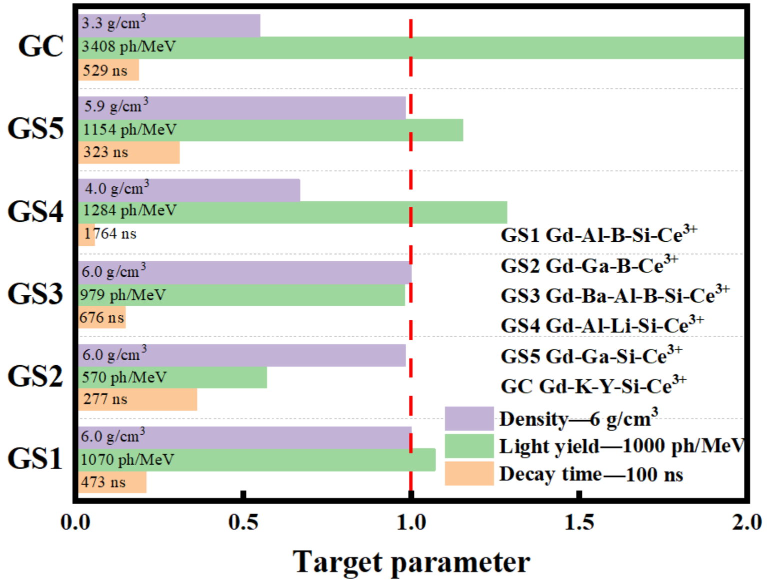
- high density, high light yield, radiation hardness, production



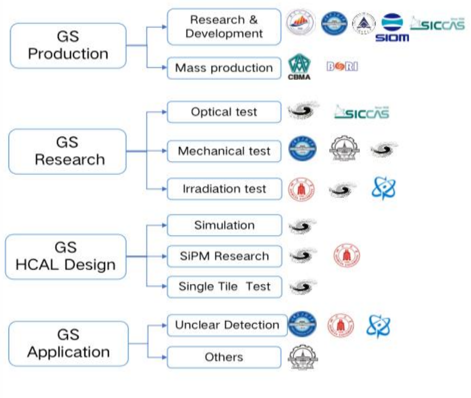


Glass Scintillator Studies

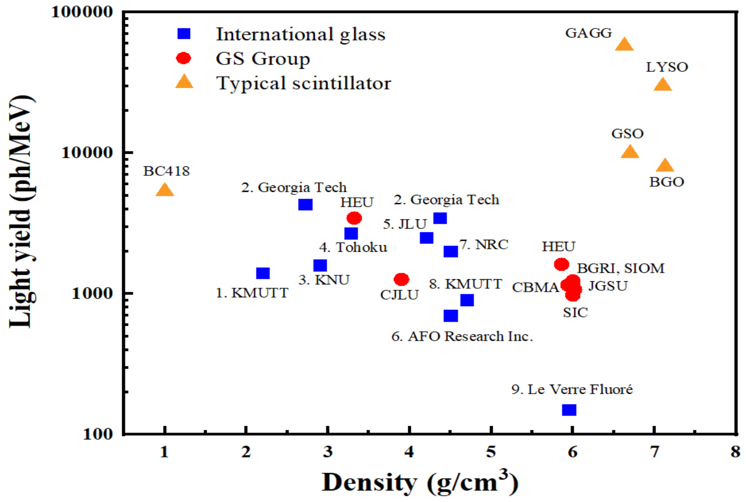




- The performance of the best glass sample: 6 g/cm3 & 1000 ph/MeV & 100 ns
- The GS collab. led by IHEP, with 3 Institutes of CAS, 5 Universities, 3 Factories.

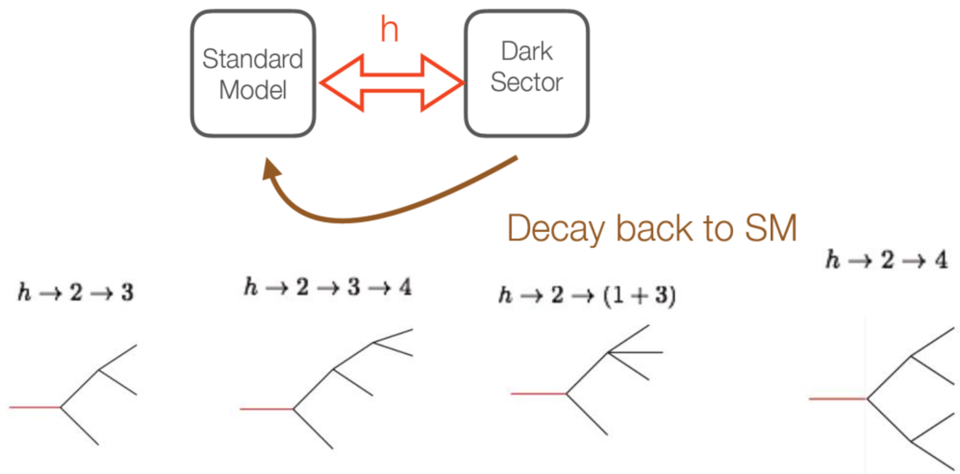


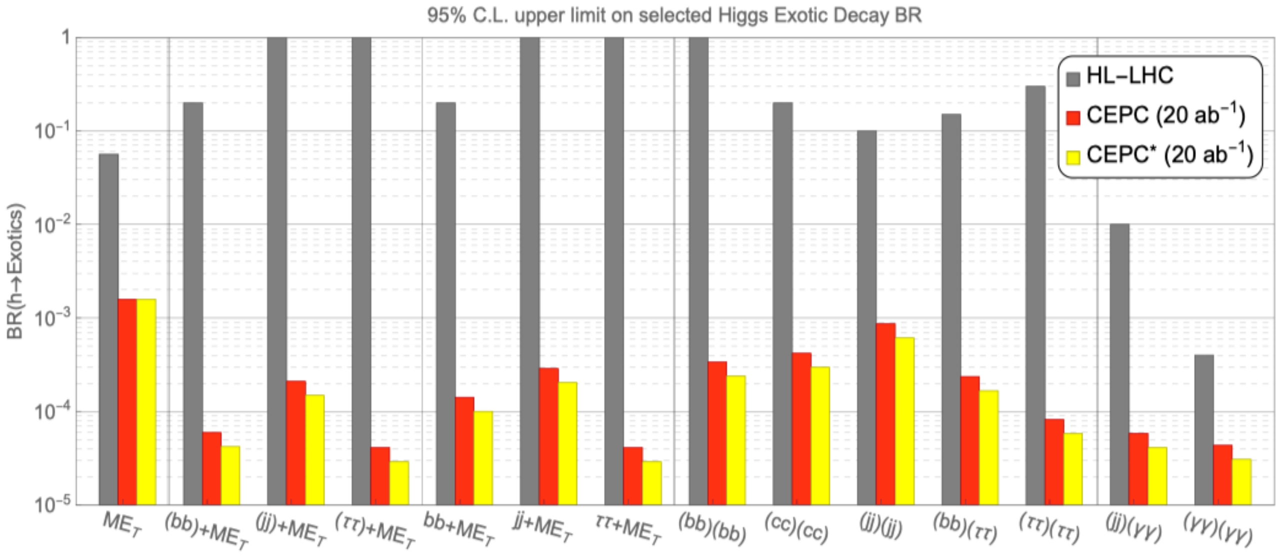
Institute of High Energy Physics, CAS
中国科学院高能物理研究所
Jinggangshan University
井冈山大学
Beijing Glass Research Institute
北京玻璃研究院
China Building Materials Academy
中国建筑材料科研究院
China Jiliang University
中国计量大学
Harbin Engineering University
哈尔滨工程大学
Harbin Institute of Technology
哈尔滨工业大学
Sichuan University
四川大学
Shanghai Institute of Ceramics, CAS
中国科学院上海硅酸盐研究所
Shanghai Institute of Optics and Fine Mechanics,
中国科学院上海光学精密机械研究所
CNNC Beijing Unclear Instrument Factory
中核（北京）核仪器有限责任公司



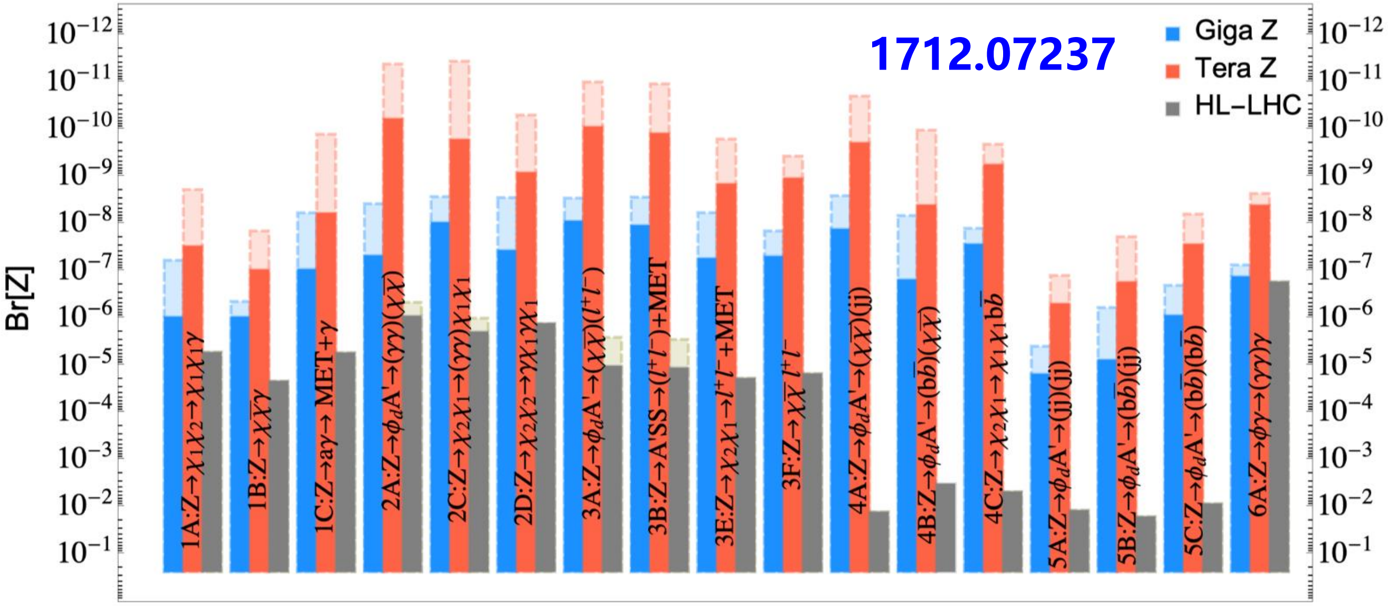
希格斯物理：新物理的探针

Higgs 衰变到BSM粒子, H→ X_1X_2





→ CEPC的Higgs 或者 Z玻色子奇异衰变末态的分支比预期测量精度将比HL-LHC提升多个数量级！



CEPC 物理：探索新物理能标

➢利用标准模型有效场理论 (SMEFT)，分别对算符参数进行独立拟合或全局拟合，CEPC对新物理的预期探索能标可达到 ~ 10 TeV！